AUTOMOBILE
ENGINEERING
VOLUME VII

VOLUME VII

IGNITION, LIGHTING, STARTING
ACCESSORIES

BY

MAJOR A. GARRARD, Wh.Ex.

AUTOMOBILE
ENGINEERING

A PRACTICAL AND AUTHORITATIVE
WORK FOR AUTOMOBILE ENGINEERS
DESIGNERS, AND STUDENTS

EDITED BY
H. KERR THOMAS
M.I.MECH.E., M.I.A.E.

VOLUME VII

SECOND EDITION

AUTOMOBILE ENGINEERING

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M.I.MECH.E., M.I.A.E.

A COMPLETE SET OF VOLUMES ON ALL BRANCHES OF THE WORK

FULL PARTICULARS POST FREE ON APPLICATION

PREFACE

THIS second edition is more than twice the size of the first and covers the field of automobile electrical equipment more completely. The treatment is based upon a reasoned explanation of scientific principles and their practical application with reference particularly to selected examples from modern practice.

Not only does the number of vehicles on the roads continue to increase, but electricity has found additional applications, while various technical developments have increased its usefulness and reliability since the first edition was published.

The author and publishers wish to thank the Editor of *The Automobile Engineer*, The Institution of Automobile Engineers, The Illuminating Engineering Society, and the firms mentioned in the text for their valuable assistance and co-operation.

PREFACE
TO THE FIRST EDITION

VOLUME VII of this work completes the series. The importance of the electrical equipment in a modern motor vehicle needs little comment. Much of its efficiency, and even more of the convenience, of a car is due to the high degree of perfection and reliability to which the electrical apparatus has been brought—whether for ignition, starting, or lighting.

Viewed as a whole, the installation is intricate and complicated, but the subject has been presented dissected to its elements, and can easily be followed with a minimum of previous knowledge of electricity. The

whole of the electrical equipment is thus dealt with, and the volume forms a complete textbook of the subject, by the help of which the initial layout of the details can be made, as well as the whole adjusted and maintained on the vehicle. By allotting a complete volume to the subject, its convenience in this respect has been considerably enhanced.

Acknowledgment is made of the assistance received from the firms mentioned in the text, and from the editor of *The Automobile Engineer* in connection with Figs. 4, 5, 6, 22, and 47.

<div align="right">H. K. T.</div>

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INSETS

SECTION XXV

IGNITION, LIGHTING, STARTING, ACCESSORIES

BY

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IGNITION, LIGHTING, STARTING, ACCESSORIES

ELECTRICAL EQUIPMENT

FROM having at one time only one electrical component, namely, the magneto, the motor vehicle has become dependent upon a multiplicity of electrical components and accessories until to-day electricity is used, not only to serve objects which could not be attained by other means, but even where it possesses no advantages over mechanical equivalents. So far has electrification been developed that the modern car, if deprived of its main electrical equipment, though fitted with a magneto, could not be used even if it could be moved. Some of the heavier vehicles would certainly be immovable without electricity, since their engines cannot be turned by hand.

With the exception of the magneto, all the electrical services are associated with and dependent upon the dynamo and the battery, and even that exception is comparatively rare on private vehicles since the rise to general favour of coil ignition systems. Ignition problems are, however, such that they can to some extent be dealt with independently of the generating and starting systems, although the underlying electrical principles are common to all. With the dynamo is associated its control devices which have been greatly improved of recent years by the introduction of constant voltage control and the consequential variation of current in accordance with the varying requirements of the battery and the vehicle.

Starting problems are broadly distinct from those of the generating system, although they cannot be entirely separated from the ignition. They are in fact responsible to some extent for the increased employment of coil ignition systems. The subjects of ignition, the generating system, starting, wiring systems, and batteries will be dealt with in that order, as far as possible without overlapping, although they are of course interrelated. A selection of examples of construction has been given, chiefly to illustrate principles, since the whole field of construction is too wide and varied to be covered in a work of this size.

Voltage. One of the questions which affect all the main and auxiliary equipment is that of voltage. Three voltages are now in common use on motor vehicles, namely, 6, 12, and 24. On most private and commercial vehicles in this country, 12-volt systems are employed while 24-volt systems are used on some of the larger commercial vehicles. The 6-volt system has been widely used in America and on many vehicles of continental manufacture.

The 12-volt system possesses certain advantages over the 6-volt system. There is less trouble with dynamo brushes due to failure as the result of dirt on the commutators. Higher efficiency is obtainable with the starter since the current for the same power output is about half. This lessens the voltage drop in the leads, switch, and other connections, and reduces brush losses. The head-lamp bulbs can also be run more efficiently.

Six-volt systems are, however, superior to 12-volt systems as regards the side-lamp bulbs and the small bulbs used for various purposes, since the fine 12-volt filaments do not stand vibration well, and these bulbs are therefore often made of greater wattage than is really necessary.

The battery cost and weight are rather higher on 12-volt systems largely because the lighting requirements, as measured in watt hours, are greater. Proper comparison can only be made on a watt-hour basis as distinct from an ampere-hour basis, since only the former takes account of the voltage.

The weight of most parts of the equipment is little affected by the matter of voltage, except that a larger dynamo is required if the output is higher. On the other hand, it may be possible to employ a 12-volt starter motor of smaller weight due to its greater efficiency.

The increasing use of 24-volt systems on heavy commercial vehicles is due to the difficulty of starting heavy compression-ignition engines with ordinary 12-volt starters; but the higher voltage is of advantage on vehicles having high lighting requirements, such as double-deck buses, since the amperage is reduced and lighter wiring may be employed. The size of wire depends upon the amperes of current it carries as the heat developed is proportional to the square of the current.

IGNITION PRINCIPLES

The ignition of the explosive mixture in the cylinders of internal combustion engines has always presented considerable difficulty. The earliest motor-car engines, in common with ordinary gas engines, were provided with hot tube ignition, in which an iron tube kept at a red heat by an external flame was connected with the combustion chamber by a valve at the end of the compression stroke. This system was much less satisfactory with motor-car engines than it had been previously with stationary gas engines, and it was soon superseded by low tension electrical systems.

In these systems a spindle entered the cylinder

through a packed insulated joint in the cylinder wall. On the inner end of the spindle was a short lever which normally made contact with a plug or projection, electrically connected to the cylinder casting. Electricity flowed through the insulated spindle and the lever to the projection without causing any sparks, but at or near the end of the compression stroke, the spindle was rotated sharply by tripping mechanism operated from the camshaft so as to separate the lever and projection slightly, as a result of which a stream of sparks passed across the gap and ignited the mixture. The making of a satisfactory gastight bearing for the spindle presented considerable difficulty, and this and other defects rendered the system obsolete many years ago.

Low tension systems were superseded by high tension systems in which a momentary current of electricity of 5,000 or more volts is forced across a small gap between the points of a sparking plug, the current being supplied by induction effects from a magneto or a battery. The magneto used was of the rotating armature type and, despite its complicated construction, proved very reliable. Prior to 1914, little else was used in this country. The rotating magnet type is of more recent introduction.

The earlier battery ignition systems utilized a trembler make-and-break, which sent a succession of sparks across the sparking plug electrodes. These systems were, however, somewhat erratic in timing and wasteful of energy, and were superseded by systems in which a spark was produced by a mechanically operated contact-breaker in the primary circuit. This system was first introduced by the Delco Company, of Dayton, U.S.A., about 1912, and has long been used to a much greater extent than the magneto in America.

The principal differences between the two methods of

producing the spark are as follows : the magneto forms an independent unit, whereas the battery system is dependent entirely on the accumulator. The rotating armature type of magneto gives a comparatively poor spark at starting and a stronger spark at speed, whereas the battery system gives the best spark at very low speed and a slightly weaker spark as the speed increases. The rotating magnet type of magneto is, however, generally as effective at low speeds as at high speeds.

In this country battery ignition systems have for some time been very widely used, having very largely replaced rotating armature magnetos on private vehicles ; but the rotating magnet type of magneto is sometimes used in preference to battery ignition, particularly on sports and racing cars. The vertical designs of the rotating magnet type are interchangeable with the battery ignition component. The change over in the case of the heavier commercial vehicles has been slower, but where magnetos are used, the rotating magnet type is preferred. Recent developments in battery ignition and particularly attention to contact-breaker and induction coil design have enabled higher speeds to be obtained with adequate voltage. The magneto and the battery system contain the same number of essential components, with the exception that the magneto forms what amounts to a small independent electric generator, whereas the battery system utilizes the accumulator which is already provided for lighting and starting. In each of the two systems the spark produced as the result of the electro-magnetic actions may be described as an induction spark as distinct from the capacity spark as produced in a Wimshurst frictional electric machine, or by the discharge of a condenser as in the Lodge ignition system.

The essential components of both the high tension magneto and the battery ignition systems are shown

diagrammatically in Fig. 1. These two systems differ only as regards the generation of the initial low tension current between the points *AB*. For the magneto system the connections in dotted lines are removed, the link *A B* then representing part of the primary circuit of the magneto. For a battery ignition system
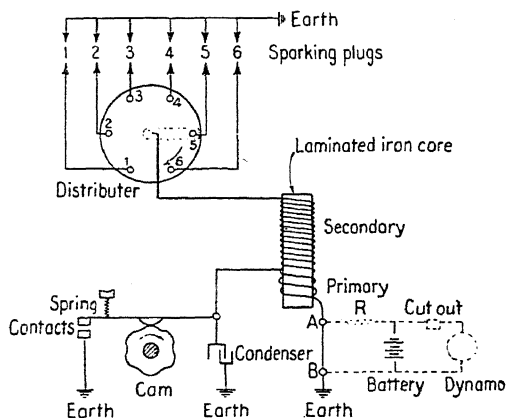
FIG. 1. ESSENTIALS OF MAGNETO AND BATTERY IGNITION SYSTEMS

the link *A B* is removed and the components of the lighting system, consisting of the dynamo, cut-out and battery are connected across the points *A B*, as shown in dotted lines. The essential components of either system thus comprise—

(1) A source of current in the primary circuit;

(2) An induction coil;

(3) An interrupter in the primary circuit;

(4) A condenser arranged across or in parallel with the make-and-break;

(5) A distributor supplying the high tension current in turn to the sparking plugs.

In both systems the spark is due to the sudden interruption at the desired instant of ignition of the current flowing in the primary circuit, this current being of the order of 5 amps., and the interruption being effected by the contact-breaker.

In both cases electric energy is stored up in the laminated soft iron cores of the induction elements during the very short period, preceding the break, that the contacts are closed. This energy may be regarded as suddenly transmitted to the secondary circuit and expended in producing a spark across the plug electrodes. The spark depends both upon the voltage instantaneously produced and the electric energy accumulated and expended at the moment of ignition.

Electrical phenomena are of such an elusive character that it is difficult to visualize electrical actions clearly. Hydraulic energies are often, however, found useful in this connection. Imagine water at a low pressure flowing along a pipe, as shown in Fig. 2, the flow being periodically checked by the closing of a valve. When the water is flowing steadily, as at A, the pressure is low, and hence it does not rise up into the high vertical pipe c of small diameter; but when the valve is closed sharply, the sudden check of the flow causes a momentary substantial increase of pressure which forces a small quantity of water up the pipe c, as indicated at B. The flow of a large quantity of water along the main pipe corresponds to the several amperes flowing in the primary circuit at low voltage, while the forcing of a small quantity of water up the small pipe, but at high pressure, corresponds to the momentary current of high voltage, and very small amperage produced in the secondary circuit. The analogy is carried still further by the provision of an air vessel d, which corresponds to the condenser and exercises a cushioning effect.

The essential and contrasting characteristics of the

high tension magneto and the battery ignition system, as regards the intensity of the spark produced at various speeds, are shown in Fig. 3. The flow in the magneto rises rapidly from zero and continues to increase, whereas in the battery system the flow at zero is
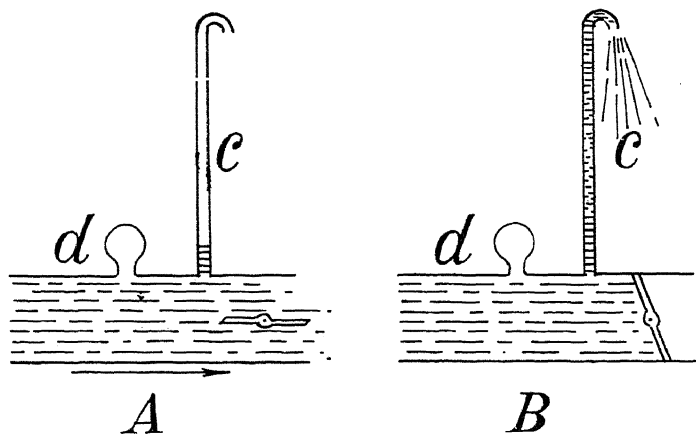

FIG. 2. HYDRAULIC ANALOGY FOR IGNITION SPARK

almost a maximum and soon begins to decrease substantially as the speed increases.

Exactly what happens between the breaking of the primary circuit and the initiation of the explosion in the cylinder is to some extent a matter of conjecture, but it may be useful to look upon it as divided into two intervals : (1) The interval between the actual break and the commencement of combustion ; this is probably of the order of ·0002 second and is equivalent to about $\frac{1}{2}°$ of crankshaft rotation with an engine turning at very high speed : (2) the rise of pressure in the cylinder from the moment of ignition, the interval until the maximum pressure is obtained being of the order of ·003 second.

The ordinary high tension spark across the plug

electrodes comprises two electric actions, one being a very fine central instantaneous spark which depends upon electric capacity, while the second is a kind of surrounding flame effect or arc which is thought to depend upon induction. The two always go together;
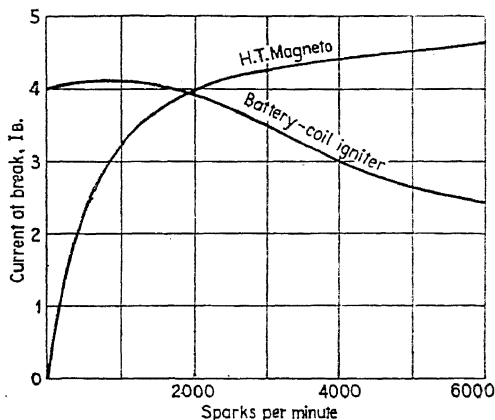

FIG. 3. SPARK ENERGY CURVES FOR MAGNETO AND BATTERY-IGNITION SYSTEMS

whether the first bright central spark is the vital element is uncertain, but it would appear to depend upon the character of the mixture. If, for example, a perfectly vaporized mixture of petrol and air is in the cylinder it is thought that the central spark may effect instantaneous ignition, but if the fuel is not perfectly vaporized, or if the insulation of the plug is in any way defective, the heating effect of the surrounding or flame-like part of the spark would seem to be necessary. Dual ignition, that is simultaneous sparks at different parts of the combustion chamber, is found in some engines to increase the power by reason of more rapid combustion; but the amount of the increase, if any, depends,

however, upon other factors, such as the design of the combustion chamber.

The study of any ignition circuit will suggest that the whole of the electrical energy in the secondary circuit is available at the plug electrodes to produce the
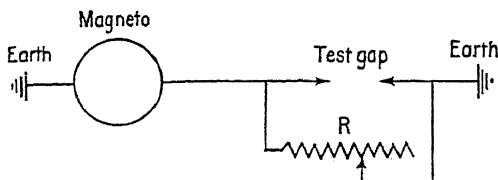

FIG. 4. ESSENTIALS OF UTILITY TEST

spark. But this is by no means always the case, primarily owing to variations in the insulation of the plugs, whether this is due to the quality of the insulation, the running temperature, or the design of the
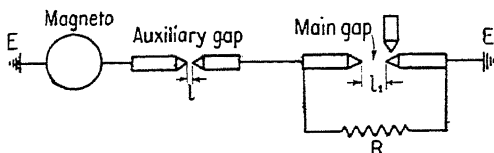
FIG. 5. TESTING EFFICACY OF AUXILIARY SPARK GAP

electrodes. For example, the resistance of the insulation of the sparking plug diminishes with increase of temperature. Further reference to this subject will be made later, but the effect can be represented diagrammatically in Fig. 4, which illustrates the essentials of what is known as a utility test. In this case the magneto or other high tension system sends a spark across a test gap which is arranged in parallel with a non-inductive variable resistance R. Clearly any leakage of current through the resistance R, which

corresponds to the insulation, etc., of the plug, will result in a decreased sparking capacity across the test gap. When testing a plug, the resistance R is gradually reduced until sparking ceases. The reciprocal $\dfrac{1}{R}$ of this critical resistance affords a measure of the ability of the ignition device to produce sparks under adverse conditions.

The use of a spark gap in the high tension lead is an old idea. The equivalent has been provided for many years in American battery ignition systems in the form of a jump spark in the distributor instead of the carbon rubbing contact of the earlier magnetos. The spark gap distributor has somewhat more recently replaced the carbon distributor on magnetos. Quite apart from the question of wear and attention, the spark-gap type of distributor improves the operation of the ignition system, particularly under adverse conditions.

This has been demonstrated by tests made on the apparatus shown diagrammatically in Fig. 5, which is based on the utility testing apparatus of Fig. 4. An auxiliary gap l corresponding to the spark gap in the distributor is arranged in series with the main gap l_1 which corresponds to the gap between the plug points. The third electrode shown to the side of the main electrodes is insulated and is provided to render the spark between the two main electrodes easier and more constant. The presence of this auxiliary gap l is found to be distinctly beneficial, particularly when there is heavy leakage due to the reduced value of the resistance R; a study of the curves shown in Fig. 6 will make this clear. These curves represent a series of experiments, each with a different value of the parallel resistance R. In each case the auxiliary gap l plotted horizontally was set to a given value, and the main gap l_1 was increased until the critical point was reached

when sparking ceased. This critical value of the gap
was then recorded and plotted vertically. Consider,
for example, the lowest curve when R has the value of
58,000 ohms. When the auxiliary gap l was set to
·06 in. the main gap l_1 could be increased up to nearly
4mm. before sparking ceased. When the auxiliary gap
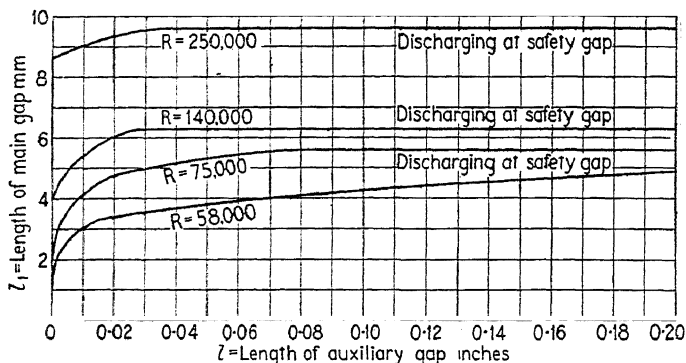
Fig. 6. Tests Showing Efficacy of Auxiliary
Spark Gap

was increased it was found that the main gap could
also be increased. When $l = 0$, the maximum value
of the main gap l_1 before sparking ceased was
definitely less than 2mm. It will thus be seen that the
provision of the small auxiliary gap ensures that a very
effective spark can be transmitted across the main
gap, and that an additional margin is thereby pro-
vided for dealing with that leakage which is so likely
to occur for various reasons. It will be noticed that
with the higher values of R corresponding to much
more efficiently insulated sparking plugs, the improve-
ment brought about by the provision of the auxiliary
gap is not so great. In making these tests a magneto
with a carbon brush distributor was used so as to

ensure that there were no other gaps in the secondary circuit than the two referred to.

The reasons for this action are as follows : During the building-up period prior to the break, the end of the secondary winding is connected to the sparking points by the carbon brush for a very short interval. If,
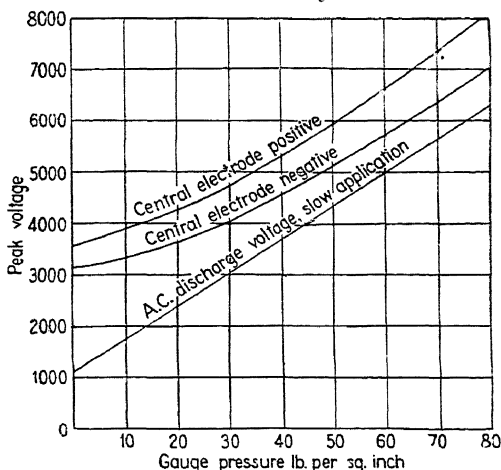
FIG. 7. COMPRESSION PRESSURES AND SPARK VOLTAGES

then, there is any leakage to earth, other than across the points of the plug, the voltage and the amperage are not built up as they should be during this period. If, however, an auxiliary spark gap is provided. the secondary winding is entirely insulated from the sparking plug, and the current builds up without leakage and hence attains a higher value, whereas without the auxiliary gap it might never attain a sufficient value owing to leakage through a hot or otherwise leaky sparking plug.

It is well known that the voltage required to produce a spark in the cylinder of an engine is greater than

in the open air, due to the higher pressure at the end of
the compression stroke. It is impossible to give any
definite relation between the voltage and the pressure
in the cylinder, since it depends upon a number of un-
certain and variable factors, such as the rate of rise
of voltage, the shape of the electrodes, the direction of
flow of the current, the turbulence, and the temperature
of the gaseous medium. Broadly speaking, however,
the insulating value of the gases in the cylinder de-
pend upon their density. The diagram Fig. 7 gives a
general idea of the manner in which the gauge pressure
(that is the pressure in excess of atmospheric pressure)
affects the voltage necessary to produce a spark, but
it must be understood that this only indicates the
general character of the relation. An electric discharge
from a point electrode to a disk electrode always has a
greater value when the point is positive than when it is
negative. The two upper curves show this. The lower
curve is obtained from a 50 cycle per second circuit.

To use again a fluid analogy, the nature of the spark
may be illustrated by reference to a diaphragm in a
pipe, one side of which is subjected to an increasing
pressure, so that ultimately the diaphragm bursts and
a rush of fluid takes place. The increase in pressure,
prior to the bursting of the diaphragm, is equivalent
to the rapid rise of voltage in the secondary circuit.

MAGNETOS

Rotating Armature Constructions. This once widely
used type of magneto includes an armature rotating be-
tween the poles of a U-shaped permanent magnet, the
armature being wound with both primary and second-
ary windings so that it also forms an induction coil.
With these components are associated a contact-breaker,
condenser, and distributor. Other types of magneto
with stationary windings and with a rotating magnet,

or a rotating soft iron inductor member, have been developed more recently.

Prior to 1914 the great majority of magnetos used in this country were of the rotating-armature type and of Bosch manufacture, and were imported from Germany, one exception to this being the Thomson-Bennet magneto, which was manufactured in this country. Both the Bosch and the Thomson-Bennet magnetos were similar in principle and differed only in a few constructional details. When the supply of German magnetos was cut off on the outbreak of war, manufacture was extended in this country, but owing to the urgent requirements at the time it was only possible at first to proceed on the same lines of construction. The Thomson-Bennet magneto some years later became associated with Joseph Lucas, Limited.
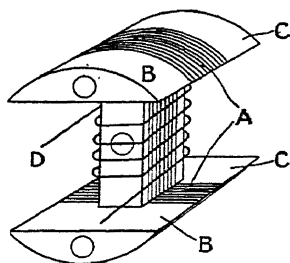

FIG. 8

The principal components of the rotating armature magneto will first be illustrated diagrammatically. The armature core is shown pictorially in Fig. 8, and a sectional view with the brass end pieces E, F is shown in Fig. 9. The core consists of a number of thin soft iron plates A, thinly insulated from one another to prevent eddy currents, and secured between two solid iron end plates B, C by long rivets. The core is shaped with a deep channel right round to receive the primary and the secondary windings D. When it has been fully wound, circular brass end pieces E, F, adapted to engage the inner races of ball bearings, are secured by screws. The winding of the armature consists of insulated copper wire. The inner few layers of primary wire comprise several hundred turns of comparatively

thick wire, about $\frac{3}{32}$ inch in diameter, and the outer secondary winding some thousands of turns of much

Fig. 9

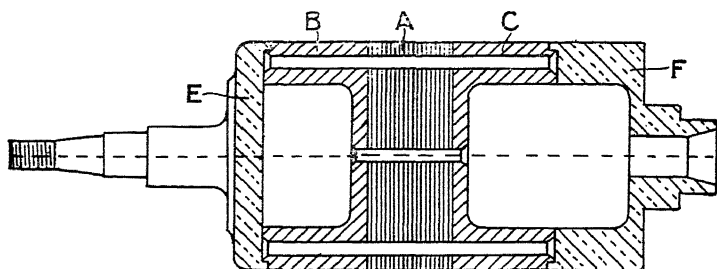finer wire. The two sets of windings to a considerable extent fill up the core, as shown in Figs. 10-12. Examination of an armature winding (or of a coil, as used in coil
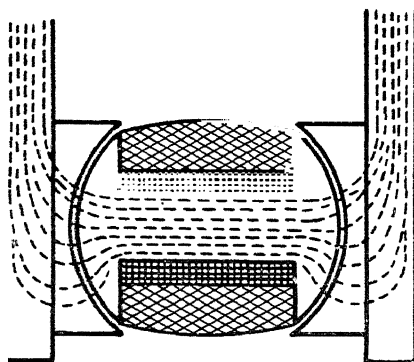

Fig. 10

ignition systems) will show that the fine wire is very thinly insulated; the insulation may, at first, appear to be inadequate, in view of the fact that the electromotive force momentarily acting may amount to more

than 10,000 volts. It must, however, be remembered that the differences of voltage between adjacent wires in any one layer is quite small, so that a mere film of insulation is sufficient to prevent a short circuit. Between adjacent layers there is a greater difference of
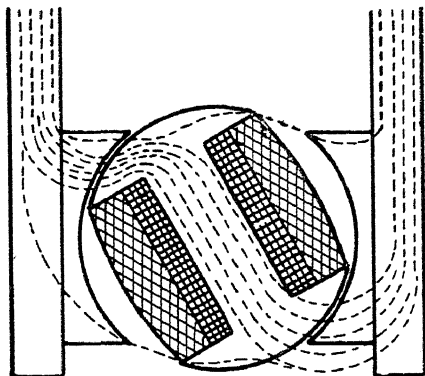
Fig. 11

potential, although this difference is, of course, very much less than the total voltage. It is, however, necessary to provide some additional insulation between the layers, such as a layer of silk.

The armature is supported in its bearings so that the outer circular metal surfaces fit with a very small air gap between the pole pieces, which are secured by screws between the ends of the U-shaped permanent magnet. The lines of force follow a closed path, being concentrated in the metal and considerably dispersed when passing through the air gap between the poles. The strain due to the presence of the air exerts a substantial demagnetizing effect. It is for this reason that a keeper, consisting of a short iron bar connecting the poles, is employed when an ordinary horseshoe

magnet is not in use. The armature normally performs
the same function in a magneto, but when it is removed
a piece of iron or steel is always used to connect the
poles and prevent demagnetization.

When the armature is in position, the lines of force
are concentrated through it, as shown in Figs. 10, 11 and
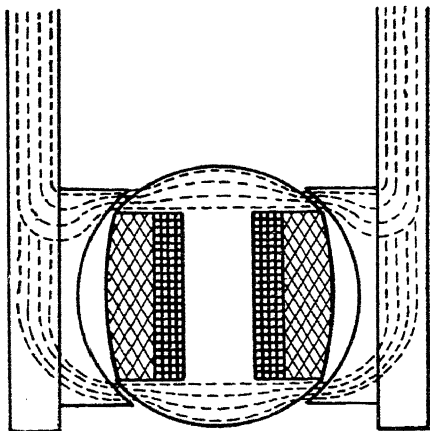
Fig. 12

12. In Fig. 10 they are shown penetrating right through
the centre of the core, and when the armature is rotated
in a clockwise direction, they are distorted by the parts
of the windings which tend to cut them, as shown in
Fig. 11. Their resistance to being stretched or cut can
be easily felt when rotating the armature by hand.
When this resistance is overcome and the armature is
turned into the position shown in Fig. 12, the lines of
force pass across the ends of the armature core from one
pole piece to the other. The coils of wire cut the lines of
force and, as a result, a momentary current of electricity
is generated, this current being indirectly utilized to

bring about a spark across the points of the sparking plugs.

The rate of cutting of the lines of force, and hence the rise of voltage, is very rapid slightly before the vertical position, shown in Fig. 12, is attained, and it is at this instant that the current flowing through the primary circuit is broken by the contact-breaker, resulting in an induced current in the secondary current of much higher voltage, in a manner which will be described later. In this way it is possible to obtain two sparks per revolution, and in multi-cylinder engines the speed of the magneto armature relatively to that of the crankshaft can be determined accordingly. Thus, in a four-cylinder four-stroke engine, the magneto runs at crankshaft speed to give four sparks in a cycle, while in a six-cylinder engine it runs at one and a half times crankshaft speed to give six sparks during the cycle.

Simms Rotating Armature Magneto. A wiring diagram for a magneto ignition system is shown in Fig. 13. Reference should also be made when studying this diagram to the detailed drawings previously referred to and to the longitudinal sectional view of the magneto, shown in Fig. 14, made by Simms Motor Units Ltd.

The main components of the magneto comprise : (1) the permanent magnets and poles pieces ; (2) the rotating armature ; (3) the contact-breaker CB at one end of the armature and rotating with it ; (4) the distributor G.

One end of the primary winding is earthed by connecting it direct to the iron core, the primary and secondary windings being connected to one another at the point C, which is further connected to the centre pin of the contact-breaker CB by a conductor 2, part of this conductor being constituted by the contact-breaker retaining screw. The other end of the secondary winding is led to a metal collector or slip-ring D, carried at

the bottom of a deep groove in an insulating ring I. The location of the slip-ring D at the bottom of the groove in the insulator avoids leakage of current.   The
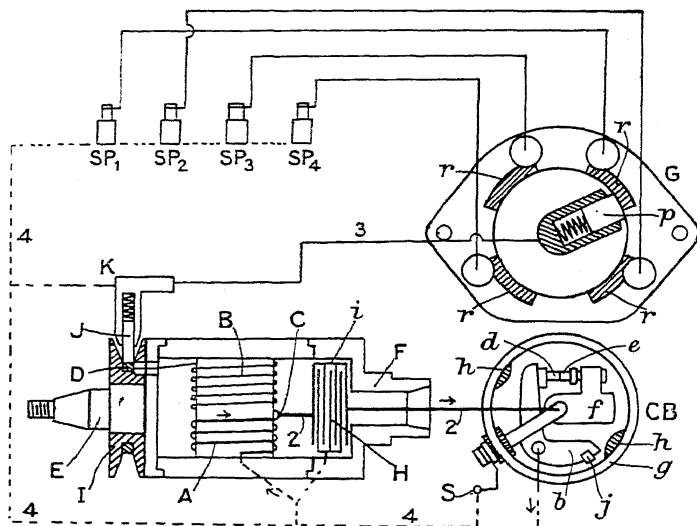
FIG. 13. MAGNETO FOR FOUR CYLINDER PETROL ENGINE

A = Primary winding.
B = Secondary winding.
b = Contact-breaker lever.
CB = Contact-breaker.
D = Collector ring.
d, e = Platinum points.
E, F = Armature end pieces.
f = Insulated block.
G = Distributor.
  = Contact-breaker case.
  = Condenser.
  = Non-rotating cams.

I = Insulator for collector ring D.
J = Collector carbon brush.
K = Safety gap.
p = Distributor carbon brush.
r = Metal segments.
S = Switch.
SP_1, SP_2
SP_3, SP_4 }
2 = Primary conductor.
3 = Secondary conductor.
4 = Earth connections.

voltage at this point is so high that the air gap between the ring D and any other metal part must be at least three-eighths of an inch to prevent a spark jumping across.   A carbon brush J and the conductor 3 carry the high tension current to the distributor carbon brush p, from which it is led to the sparking plug
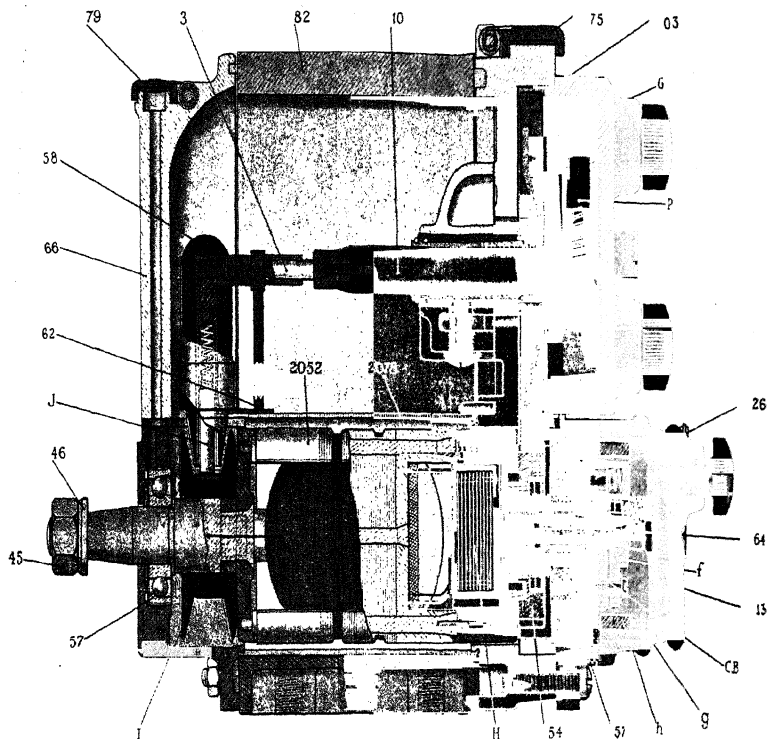
FIG. 14. SIMMS ROTATING ARMATURE MAGNETO

G. Distributor.
f. Insulated block.
P. Distributor carbon brush.
10. Distributor carbon holder
13. Timing lever cover.
C.B. Contact-breaker.
26. Earth brush.
g. Contact-breaker case.
h. Cams.

45. Driving spindle and disk nut.
46. Driving spindle washer.
I. Slip ring.
2052. Wound armature core.
54. Distributor drive pinion.
57. Ball bearings.
58. Collector carbon holder.
J. Collector brush and spring
3. Conductor.

62. Safety gap plate.
H. Condenser.
64. Contact-breaker retaining screw.
66. Cover plate.
75. Distributor end-plate oil flap.
2078. Cover plate for armature.
79. Cover plate oil flap.
82. Magnet.
03. Distributor driven pinion.

33

in that one of the four cylinders in which the mixture is fully compressed ; a compact condenser H is arranged inside one of the armature end pieces F, one set of plates being connected to the low tension conductor 2, while the other set is earthed by a connection to F.

The contact-breaker CB rotates with the armature and breaks the primary circuit in the winding A, at or near the point when the voltage reaches its maximum. A bent lever b is pivoted at the angle on a pin carried by a base on the end of the armature spindle. Between the pin and the hole in the lever is interposed a fibre bush, the primary purpose of which is to provide a pivot which does not call for lubrication. The lever b is acted on by a spring, which tends to press the platinum tipped point d on the arm into contact with a similar, but adjustable point e, carried on a block f insulated from the base, but connected to the fastening screw and conductor 2. The spring also serves to make electrical connection between the lever b and the base, which is earthed by a carbon brush. The whole of the parts just described rotate with the armature inside the timing casing g, provided with two inwardly projecting segments or cams h.

Twice in each revolution the fibre projection j on the other arm of the bent lever b makes contact with a segment h and the platinum points d, e are separated, thus breaking the primary circuit. As a result a spark is produced in one of the cylinders in a way which will be described shortly. The high tension lead 3 is connected in turn to the sparking plugs by means of the distributor G which consists essentially of: (1) a rotating carbon brush p carrying high tension current from the conductor 3, and (2) an insulated shell, in the inner circular surface of which are embedded metal segments r connected one to each sparking plug.

The primary and the secondary circuits must both be

individually complete, though one or more conducting elements may be common to both. The primary circuit consists of the primary winding A, conductor 2, block f, platinum points d, e, lever b, and connection to earth. The secondary circuit consists of the secondary winding B, collector ring D, carbon brush J, conductor 3, carbon brush p, distributor segment r, sparking plug lead, spark gap, earth return 4, and primary winding A.

The manner in which the magneto produces a spark will now be considered in more detail. Just before the points d, e of the contact-breaker separate, the cutting by the armature windings of the lines of force between the magnet poles causes current to flow through the winding A and the primary circuit. When the points open, the stoppage of the flow in the primary winding induces a momentary current in the secondary circuit B of much higher voltage, sufficient to cause a spark across the gap of one of the sparking plugs. The engine or frame forms the earth return for both primary and secondary circuits. Should the voltage in the secondary circuit become excessive by reason, for instance, of the disconnection of a lead to a sparking plug, the current escapes to earth through the safety gap, that is the sparking plug is short circuited; this avoids the possibility of an excessive rise of voltage in the secondary circuit and consequent breaking down of the insulation. The safety gap is usually about $\frac{3}{8}$ in.

The magneto is switched off by a switch S, which connects the central screw and block f to earth, through a spring contact mounted on the inside of the moulded cover 13.

The distributor is driven at crankshaft speed from the armature by toothed gearing giving a 2 to 1, or a 3 to 1 ratio, according to whether the magneto is intended for a four- or six-cylinder engine.

The contact-breaker CB with rocker b and block f can be removed as a whole when the centre screw is removed. The ignition point is advanced or retarded by a rotary adjustment of the contact-breaker case g with cams h, the adjustment being usually made by hand. This method suffers from the defect that the
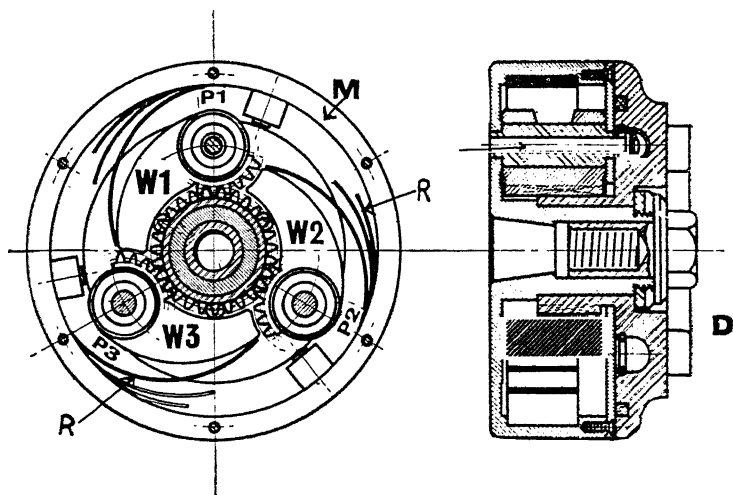
FIG. 15. SIMMS CENTRIFUGAL ADVANCE MECHANISM

contact points are not always separated at the instant that the rate of cutting of the lines of force is a maximum, so that the intensity of the spark varies with the speed. Automatic advance-and-retard devices and impulse starters are usually mounted on the driving spindle.

The Simms centrifugal advance mechanism is enclosed in a drum mounted at the driving end of any standard magneto, and varies the angle between the external driving member and the main shaft of the

magneto, through a range of about 30 degrees, in addition to the ordinary hand control.

The main casing M, Fig. 15, is fixed on the coned and screwed end of the magneto spindle, and the driving member D carries one element of a Vernier coupling, by which it is driven. The sleeve-like boss of the driving member carries a central toothed wheel with which engage three toothed planet sectors P_1, P_2, P_3 mounted on spindles in the casing M, and integral with weights W_1, W_2, W_3. When the mechanism rotates in a clockwise direction, the weights fly out in opposition to the curved plate springs R; and this movement rotates the whole casing M forward in a clockwise direction relatively to the central toothed driving member D, thus automatically advancing the spark in accordance with the speed. The mechanism usually begins to operate at a minimum speed of 500 r.p.m.

Fig. 16. Simms Magneto Drive

Some kind of flexible coupling between the driving end of the magneto spindle and the driving element from the engine is essential, since accuracy in the alignment cannot be relied upon, either in the course of manufacture, or during repair or replacement. Further, it is essential that provision should be made to adjust the angular relationship between the magneto armature and the driving element, so as to ensure that the magneto can be properly advanced. It is desirable that the magneto should be so arranged that it fires on the dead centre when fully retarded. Both of these

requirements are met by a flexible vernier coupling, an example of which is the Simms, shown in Fig. 16. A serrated rubber clutch member is interposed between two half coupling members, the numbers of serrations

STATIONARY ARMATURE
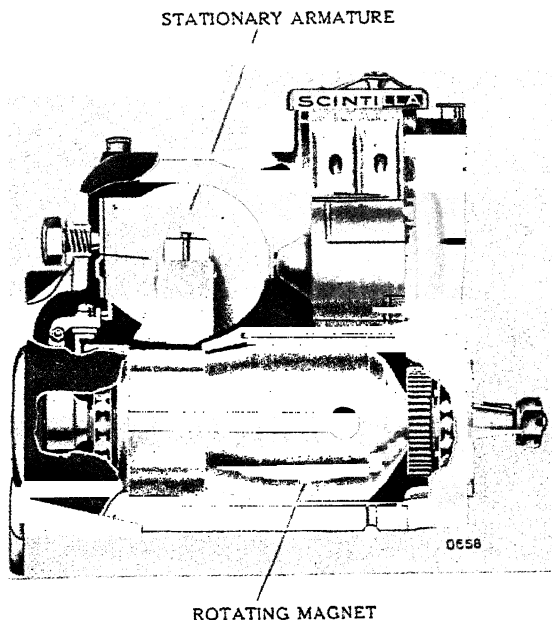
ROTATING MAGNET

FIG. 17. SCINTILLA ROTATING MAGNET MAGNETO

on the two sides differing by one, thus forming a vernier connection such that, when the rubber member is removed and turned round to a fresh position, the coupling parts will be adjusted relatively to one another through a very small angle.

Scintilla Rotating-Magnet Magneto. This magneto of the horizontal type affords a well tried example of the rotating magnet construction. A longitudinal section is shown in Fig. 17, and a combined pictorial

and diagrammatic view is shown in Fig. 18, for a four-cylinder engine. This design differs from that previously described in that the most robust part in any magneto, that is, the permanent magnet, forms the rotating element, while the delicate parts, such as the contact-breaker with its contact points and the armature 55, are stationary. The rotating permanent magnet 1 is of U shape, with N. and S. poles adjacent to one another at one end. To each pole is attached a laminated pole piece, the outer surfaces of which are circular, so that they rotate with a small air gap within the stationary laminated pole pieces 2, the upper ends of which are connected by the laminated armature core 3. This careful lamination prevents unwanted eddy currents, and is an important factor in obtaining effective operation.

The poles of the magnet produce in the armature core 3 a magnetic flux, which is reversed twice every revolution, and the primary circuit 4, shown in black lines, is broken when the magnetic forces are at or near their maximum value. In this way the high tension current is momentarily developed in the secondary winding 13, and is conveyed to the sparking plugs 1, 2, 4, 3, as required, by the distributor. The rocker arm 7, pivoted at 6, carries a fibre heel which engages a cam 5 secured to the driving spindle, and having two lobes, since this magneto is of the four-cylinder type. The movable contact screw 8 is earthed by the spring 9, which acts upon the rocker arm 7; and the long contact screw 10 is mounted on the insulated carrier 11, the screw leading through the primary circuit back to earth 18, as represented by heavy dotted lines. The primary circuit thus runs from earth, spring 9, the contact points 8, 10, and primary winding back to earth.

The secondary windings, shown in fine lines outside
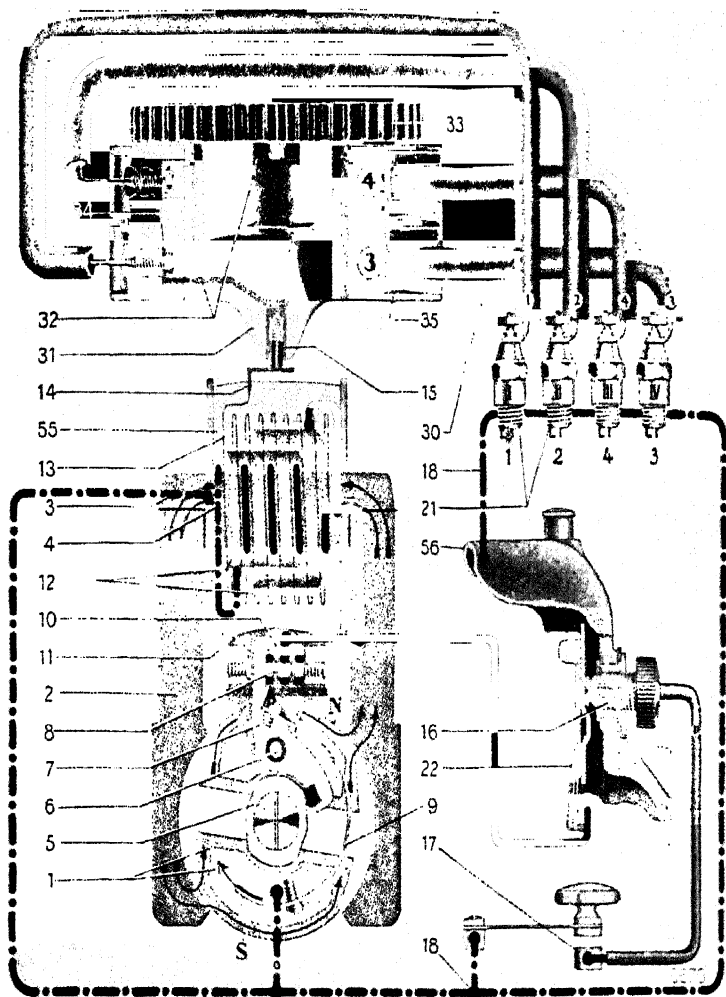
FIG. 18. SCINTILLA ROTATING-MAGNET MAGNETO WITH CONNECTIONS

(T.8756)
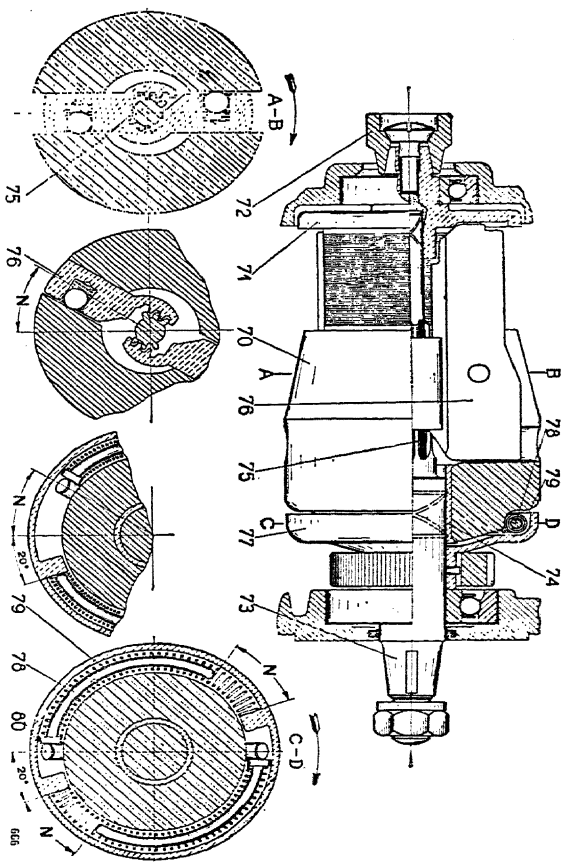
Fig. 19. Scintilla Rotating Magnet with Automatic Advance

and adapted to slide radially, in accordance wi
speed, in the gap between the two poles of the magnet
and its laminated ends. To eliminate friction, balls
are let into the weights.

The housing 77 is securely pressed on the driving
shaft 73, and encloses the governor springs 79, which
surround curved distance bolts 78. The driving shaft
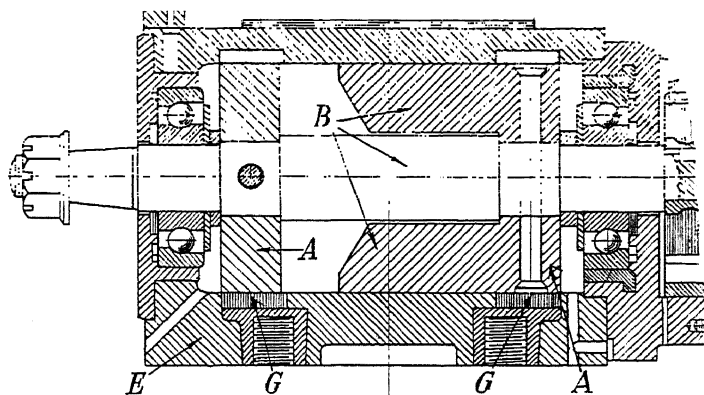
FIG. 20. B.T.-H. POLAR INDUCTOR MAGNETO

73 rotates the magnets only through the medium of the
teeth 75 engaging with the centrifugal weights 76.
This drive is, however, controlled by the action of
centrifugal force and by the springs 79. At quite low
speeds, the centrifugal weights 76 tend to fly outwards
and through the toothed mechanism and the springs
cause the magnet 70 to advance in the direction of
rotation. The governor springs 79 are compressed
against stops in the housing 77 by means of the pins 80
on the magnet, the movement, that is the maximum
angle of advance, being limited by the distance bolts 78.
The toothed driving wheel for the distributor is mounted
on the sleeve part of the housing 77, and so rotates

with the driving shaft. Both the contact-breaker cam 72 and the magnets advance relatively to the shaft 73 as the speed increases, so that there is no variation in the intensity of the spark as the advance is varied.
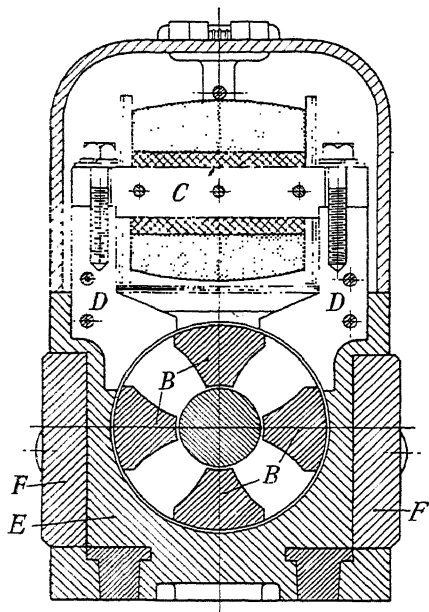
FIG. 21. CROSS-SECTION OF B.T.-H. POLAR INDUCTOR MAGNETO

B.T.-H. Polar Inductor Magneto. Rotating soft iron inductors in this machine, made by the British Thomson-Houston Co., co-operate with laminated elements passing through the armature, to produce, when required, four sparks per revolution, so that it is particularly adapted for 6, 8, or more cylindered engines. A longitudinal section through the rotor is shown in Fig. 20, and a central transverse section in Fig. 21.

The rotor consists of a 25 per cent nickel-steel shaft on to which the inductors are forced and riveted. Each inductor is made with a ring shaped end A and two fingers B extending longitudinally, the four fingers overlapping and alternating with one another.

The armature core C is mounted on laminated armature poles D cast into the top of the aluminium
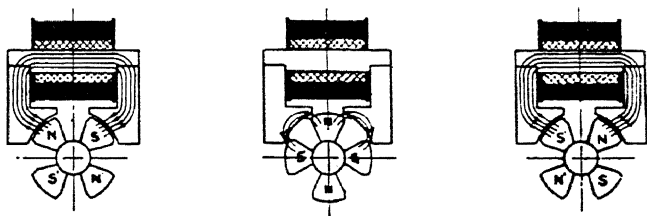
FIG. 22. FLUX REVERSAL THROUGH LAMINATED CIRCUIT

body E. The polarity of the fingers B alternates as they rotate in the magnetic field formed by two cobalt plate magnets F secured in side recesses and in intimate contact with two annular laminated poles G cast in the body E.

As the armature rotates, the polarity of the inductors changes, as shown in Fig. 22, and the magnetic flux in the circuit formed by the core C, the armature poles D and the fingers B, is thus reversed four times per revolution. The primary circuit is made and broken in the usual manner by a cam on the end of the shaft and a rocking lever.

The manufacture of the secondary, particularly in rotating armature magnetos, is a matter of considerable difficulty in view of the high voltage of the current, and the very small space available. The enamelled copper wire used is of extremely fine gauge, usually about ·004 in. in diameter, and each armature requires about 1,500 yards. The enamel must be

to the armature core 6 by the core connecting pieces 4, 5. The magnetic circuit from the N. to the S. magnet poles is thus completed through the long pole shoes, the core connecting pieces 5, the core 6, the core connecting pieces 4, and the short pole shoes 2. The long pole shoes and the short pole shoes are thus at their ends alternately N. and S. so that the magnetic flux through the core is reversed six times for every revolution of the magnet. This alternating flux induces a low tension current in the primary 7, and the sudden interruption of this current by the opening of the contact-breaker points induces, in the secondary winding 8, a high tension current which is conducted by the lead 9 to the central contact 10 of the distributor head 19. From the distributor rotor 11, the high tension current is distributed through the electrodes 12 to the plugs.

The primary winding is connected in the usual way to the fixed contact point carrier 15 and rocker arm 14, the former being earthed through switch 26 to cut out the magneto. The distributor head 19 is firmly secured to a cylindrical casing (not shown), rendering the whole magneto dust- and water-proof.

The condenser is connected as usual in parallel with the contact points ; it is of annular form and is located between the inner primary winding 7 and the outer secondary winding 8.

The rotor 30 is coupled to the driving spindle 20 by the automatic advance device, which is unique in that no springs are employed. Two packs of centrifugal weights 21, 22 consisting of laminations of various shapes and weights, are pivoted on guide pins 29 carried by the rotor, and centrifugal force is resisted by the cams 23 on the driving spindle. The cam 23 drives the rotor by means of the weights, the cam engaging heels on the weights and thus acting through

the heels and the guide pins or weight pivots 29 on
the rotor. As speed increases, the centrifugal weights
move outwards and force the cam 23 to advance
relatively to the pins 29. The weights reach the limit
of their travel in succession, and are put out of action
when they engage a rotating cylindrical shell. Any
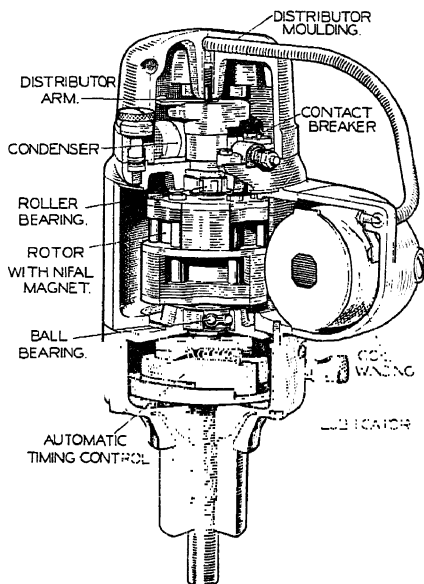
FIG. 24. LUCAS VERTICAL MAGNETO

desired relation between speed and advance can be
obtained by varying the shape and the weight of the
plates. The range of advance in relation to the speed
always remains constant since it cannot be affected
by set of the springs. The friction brake tends to
steady running by counteracting the shocks set up
by the break of the magnetic field.

Lucas Vertical Magneto. These magnetos are of

the rotating magnet type and are mounted vertically or nearly so in the same way as the contact-breaker and distributor assembly of a battery ignition system, a pictorial sectional view being shown in Fig. 24. The coil with its primary and secondary windings, core and pole pieces is housed in a lateral extension of the main casing. Certain of the details of construction are very similar to corresponding parts in the coil ignition systems with which these magnetos are interchangeable. The central driving spindle, rotating at camshaft speed in a plain bearing, is connected through the automatic timing control to the rotor which is mounted in a ball bearing and a roller bearing.
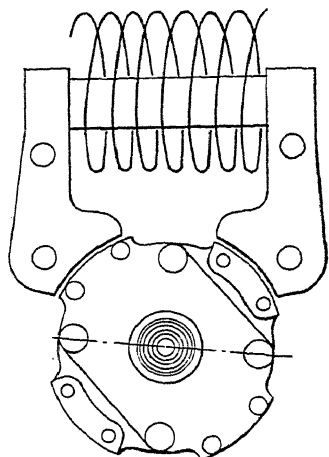
Fig. 25

Above this are arranged the contact-breaker and the distributor arm so that only the more robust components rotate.

The rotor consists of a single circular permanent magnet built up on its outside with four, six, or eight laminated pole shoes according to the number of cylinders in the engine, the poles being alternately N. and S., and arranged on the upper and lower parts of the rotor. The magnet is made of a special nickel-aluminium-iron alloy to which the trade name "Nifal" is applied, and possesses better magnetic properties than the cobalt steel alloy particularly in its resistance to demagnetization.

The magnetic circuit for a four-cylinder engine is

shown in plan in the diagram Fig. 25. The core through the induction coil is connected to two fixed laminated soft iron pole pieces which are so curved at their ends that the air gap between them and the poles of the

Auxiliary weights | Main weights

Slow speeds—Auxiliary weights assist main weights

Medium speeds—Effect of auxiliary weights balanced

High speeds—Auxiliary weights oppose main weights
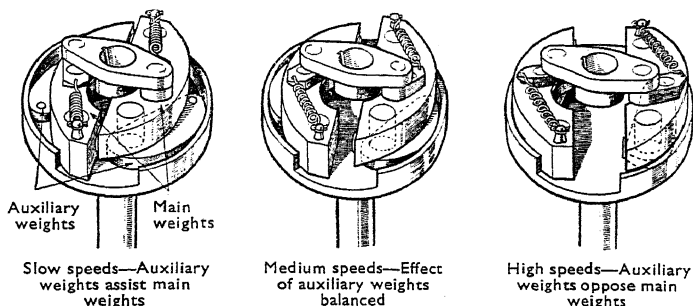
FIG. 26. LUCAS MAGNETO, AUTOMATIC ADVANCE

rotor is as small as possible to avoid magnetic leakage losses. These pole pieces extend vertically the full depth of the rotor and form, with the soft iron core and the highly magnetized metal of the rotor, the closed magnetic circuit. As the rotor turns, the direction of the magnetic flux in the core is continually reversed.

Three positions of the automatic advance mechanism corresponding to slow, medium, and high speeds are shown in Fig. 26. The main weights are pivoted at their ends on the action plate, which is carried at the upper end of the driving shaft, and is formed with a flange round part of its edge. Short levers controlled by tension springs connect the middle points of the main weights to a two-armed lever which rotates the rotor above it, these levers forming the driving connection and varying their angle as the speed increases, so that the angular relationship between the driving shaft and the rotor also varies in the desired manner. The springs oppose the centrifugal forces, tending to

make the main weights pivot outwards. Auxiliary weights are also provided to slow the rate of advance at the top speed range so that a more correct timing curve may be obtained. One end of each auxiliary weight is pivoted to the underside of the main weight at the free end. At low speeds, the auxiliary weights move outwards owing to centrifugal force, and to a small extent assist the outward movement of the main weights. As speed increases, the free end of each auxiliary weight comes into contact with the flange or wall of the action plate at a point well remote from its pivotal connection with the main weight. As speed increases further, the centrifugal force exerted by the main weights on the auxiliary weight brings about a rolling action of the flange, and the point of contact moves closer to the pivot until, as shown on the right of the figure, the centrifugal force acting on the free end of the auxiliary weight opposes the centrifugal force acting on the main weight.

FIG. 27. LUCAS CONTACT-BREAKER

Some details of the contact-breaker mechanism are shown in Fig. 27, the high tension distributor arm being removed. A light form of spring-controlled rocker arm with fibre rubbing piece is provided, and the adjustment of the contact gap is effected in a

convenient manner by mounting the stationary contact on a contact plate which is clamped in position by two screws after the gap has been adjusted. A gauge of the order of ·012 in. is usually provided for initially setting contact-breaker points, but provided that there is a gap at all, considerable variation from the initial setting has very little effect upon the running of an engine, although an excessive gap will limit the maximum sparking speed. The rocker arm is short and of very light design with a small moment of inertia about its pivot so that the tendency to "flinging," that is, lifting off the cam, at high speeds, is reduced to a minimum, without excessive spring pressure. This part is very similar to the corresponding part in the Lucas coil ignition system described later. The principles underlying high-speed operation are also discussed later. This magneto will function at speeds far higher than those called for by present-day racing requirements and will, at the other extreme, operate at the slow sparking speed of 25 r.p.m.

Impulse Starters. Reference has already been made to the difficulty of starting with the rotating armature type of magneto, since only weak currents can be produced at low speeds. This is particularly important in the case of heavy commercial engines, which require the exertion of considerable physical force to start by hand, or the expenditure of a very heavy starting current. It is for this reason that impulse starters have been provided for use in connection with magnetos.

Comparatively slow movement of the engine is sufficient to enable an explosive mixture to be drawn into the cylinders, two turns being generally sufficient, although this varies greatly with different carburettors. To avoid the necessity for rapid rotation, the impulse starter holds back the magneto armature for a time, so that, when released, it may be rotated rapidly by

a spring and produce an intense spark. Fig. 28 shows an impulse starter made by the British Thomson-Houston Co., and Fig. 29 shows the locking pawls in the operative and inoperative positions.

The device consists essentially of two members ; the driven member C is fixed to the armature spindle and the driving member I encloses most of the apparatus, being driven by a connection to the studs. The driving member I rotates close up to the member A which is fixed to the magneto casing. Except when the engine is running quite slowly, the driving member I and the driven member C rotate together, being locked by plungers F mounted in guides E, and pressed outward by flat springs G, so as to engage recesses in the periphery of the driving member. The heavy inner end of each plunger carries a pivot for a pawl K which is provided with a balance weight, so that when the speed is sufficient the pawls assume the position shown on the right of Fig. 29, and rotate clear of the driving member. When, however, the driven member is rotated slowly, one of the pawls when in the top position will tilt and engage the catch B on the fixed member A, as shown in Fig. 28 (c) and on the left of Fig. 29. This will check the movement of the armature, and any further rotation of the driving member I will cause an angular displacement between it and the driven member C, thereby winding up the clock type spring J. At the same time the end of one of the plungers F will travel along the inclined surface of the cam ring H, thereby pushing the plunger toward the centre against the resistance of the flat spring G, until the pawl K is released from the catch B. The armature is then free to rotate and the tension of the wound-up spring J will give it a sudden impulse. At the proper instant the contact points separate and a spark of considerable intensity is thus produced. As

B = HARDENED CATCH.

A = FIXED MEMBER

F = PLUNGER

I = DRIVING MEMBER

J = HELICAL SPRING

D = SPECIAL NUT

C = DRIVEN MEMBER

K = GRAVITY PAWL

FIXED MEMBER
SHOWING STOP FOR PAWL
(c)

SECTIONAL ELEVATION.
(b)

H = CAM RING.   E = GUIDE PIECE   F = PLUNGER

G = FLAT SPRING.

K = GRAVITY PAWL

VIEW FROM REAR
WITH FIXED MEMBER REMOVED.
(a)
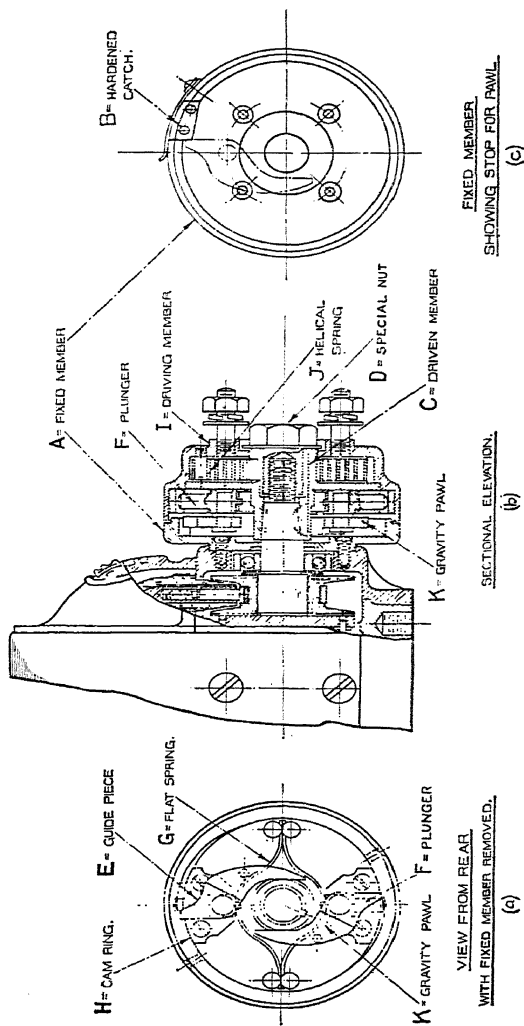
FIG. 28. B.T.-H. IMPULSE STARTER

soon as the driven member has caught up the driving
member, the plungers *F* slip into the recesses in the
driving member so that the driving and driven members
rotate together.

Laminated Poles. In all electrical apparatus in which
masses of iron are subjected to alternating magnetiza-
tion, electrical eddy currents are set up by electro-

VIEW OF DRIVEN MEMBER, SHOWING
PAWL ENGAGED WITH STOP OF FIXED
MEMBER.

INNER FACE OF DRIVEN MEMBER.
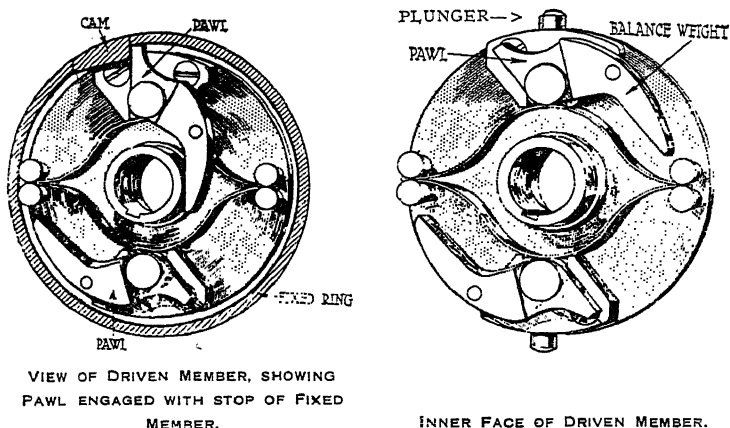
FIG. 29. LOCKING PAWLS OF B.T.-H. IMPULSE STARTER

magnetic induction. These eddy currents are dissi-
pated in the form of heat, and it is desirable to avoid
such a loss of energy. For this reason the poles or
cores are, wherever possible, built up of thin sheets,
slightly insulated from one another by thin sheets of
paper or varnish. The laminations are disposed in the
direction in which the magnetic flux changes take
place, so as to guide the flux and avoid irrelevant effects.
For example, better results are obtained if the old
solid iron pole-pieces in the ordinary rotating-armature
magneto are replaced by laminated pole-pieces, with

the laminations running in the direction of the plane of rotation. In dynamos and starter motors the armature core and the field magnet poles are always laminated in the plane of rotation. The core of an induction coil is not solid but consists of a bundle of soft iron rods.

Steel for Magnets. Soft iron possesses no capacity for retaining magnetism. It can be magnetized to a high degree of intensity and demagnetized by the cessation of the magnetizing current with almost inconceivable rapidity. Steel, on the other hand, can be magnetized by a powerful electric current and, when the current ceases to flow, it will retain a substantial proportion of its magnetic properties. The strength of the magnet depends upon the amount of carbon in the steel, but the addition of a small percentage of other substances exercises an even stronger effect. The material which has been most widely used for a number of years for this purpose is steel containing five to six per cent of tungsten. Steel containing two per cent of chromium has, however, been used to some extent and is very little inferior. Other metals have also been added in small quantities to steel to increase its magnetic retaining properties and magnetic strength. Cobalt is several times as effective as tungsten in this connection, but special alloys such as nickel-aluminium-iron alloys recently introduced have even superior characteristics. It is generally agreed that the best criterion of magnetic quality is the maximum value of the product of the coercive force and the remanence. This product known as $(BH)_{max}$ has varying values, depending on the quality of steel. Typical values for steel having varying percentages of cobalt, tungsten, and chromium are given on page 44.

It will thus be seen that a 35 per cent cobalt steel magnet is about three times as effective for a given

Steel				$(BH)_{max}$
35% Cobalt .	.	.	.	910,000
15% Cobalt .	.	.	.	615,000
9% Cobalt .	.	.	.	455,000
6% Tungsten	.	.	.	287,000
2% Chromium	.	.	.	245,000

volume and weight as a tungsten steel magnet. The cost is, however, greater.

BATTERY IGNITION

Wiring Diagram. The essentials of a battery or coil ignition set are shown in Fig. 30. These include—

1. The battery A.

2. The induction coil B, by means of which the low voltage current in the primary circuit is transformed to high voltage current in the secondary circuit.

3. The contact-breaker, which closes the primary circuit and opens it at the exact instant in the engine cycle of operations required for ignition.

4. The condenser, which reduces sparking at the contact points when they are separated and performs a useful function in connection with the transformation of the current.

5. The distributor D, which conveys the high voltage current in the secondary circuit to that one of the sparking plugs which immediately requires it.

6. The switch C, for closing and opening the primary circuit when it is desired to start and to stop the engine.

The diagram makes it clear that the primary circuit is completed through the battery A, the switch C, the primary windings (thick) in the induction coil and the contact breaker points, the return being completed through the engine and the frame of the vehicle. The
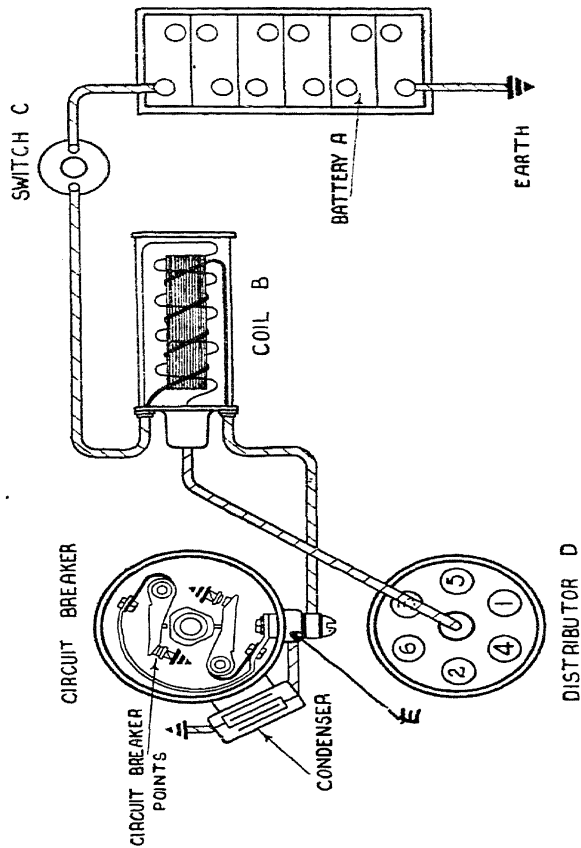
SWITCH C

BATTERY A

EARTH

COIL B

CIRCUIT BREAKER

CIRCUIT BREAKER POINTS

CONDENSER

DISTRIBUTOR D

Fig. 30. Delco-Remy Battery Ignition System

condenser is as usual connected across or in parallel with the contact-breaker. The secondary circuit includes the battery, switch, secondary windings (thin) in coil B, distributor and sparking plugs. One or two pairs of contact-breaker points may be provided. These will be referred to later.

Delco-Remy Single Breaker. Battery ignition contact-breakers and distributors are generally mounted on a vertical or slightly inclined shaft driven from the crankshaft directly or indirectly through skew gearing always at camshaft speed. In this respect it differs from the magneto, in which the speed depends upon the number of cylinders, since most magnetos produce only two sparks per revolution, so that while a four-cylinder magneto rotates at engine speed a six-cylinder magneto rotates at $1\frac{1}{2}$ times engine speed. In coil ignition systems, the cam always turns at camshaft speed, and the number of cylinders is equal to or is exactly double the number of lobes according to the design of the apparatus.

In Fig. 31 is shown a vertical section through a six-cylinder ignition apparatus made by Delco-Remy and Hyatt, Ltd., together with a plan view of the contact-breaker. The whole of the apparatus is enclosed in the distributor housing and the cap, the former being mounted on the vertical guiding shaft and held in position against rotation by means of a connection to the manual or other ignition advance control. Mounted in the upper part of the distributor housing is a plate or base a carrying a contact-breaker which comprises a fixed contact-point b, and a movable contact point mounted on the end of the breaker lever which is pivoted to the base a, and has low tension current led to it from a terminal through the spring which holds the fibre heel c against the six-lobed cam which is rotated at engine speed by the shaft. The gap

between the points recommended when resetting is between 0·018 and 0·024 in.

The distributor is contained in the cap, the rotor, of insulating material, being carried by the upper end
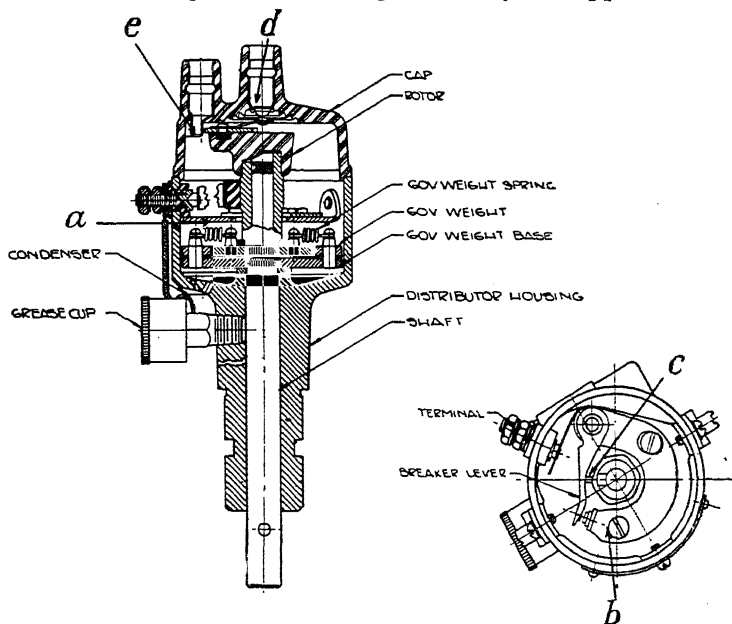
FIG. 31. DELCO-REMY SINGLE BREAKER CONSTRUCTION

of the sleeve on which the cam is mounted. High tension current from the induction coil is led to the central connection *d* and thence to the spring contact carried by the metal pointer on the end of the rotor arm. This pointer moves close to each of the six distributor elements *e* in succession, but does not actually touch them, the distributor thus being of the jump-spark type.

In the bottom of the distributor housing is a centrifugal advance device by means of which the angular

relation between the shaft and the sleeve carrying the cam is adjusted in accordance with the speed. This is effected by governor weights pivoted to the base and controlled by springs, so that their position, and
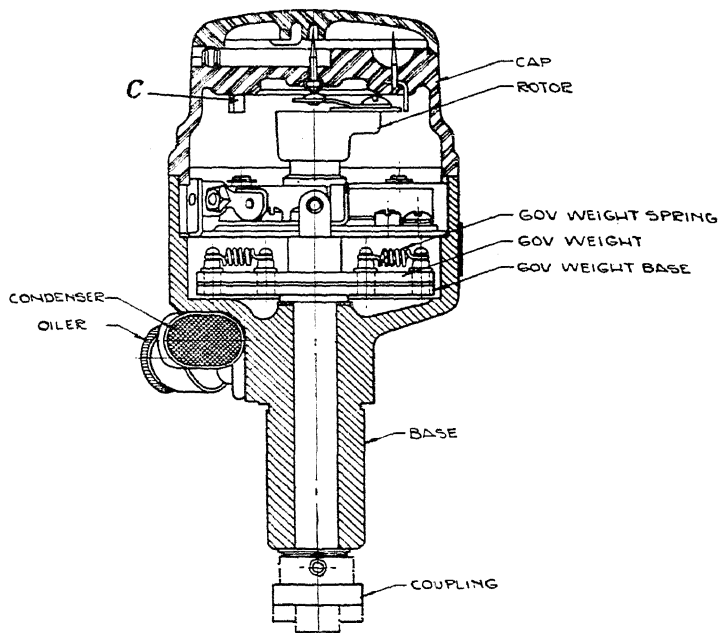
FIG. 32. DELCO-REMY DOUBLE BREAKER CONSTRUCTION

hence the advance given to the cam and the distributor rotor, depend upon the speed. Centrifugal advance devices have been described in connection with magnetos.

Delco-Remy Double Breaker. In six- and eight-cylinder ignition systems, the lobes on the cams are very close together, and a modified construction has been introduced in which the number of lobes may be halved. This avoids the necessity for such extreme

accuracy in the shape of the cam, and moreover it distributes the wear between two contact-breakers which fire alternately and must be synchronized with considerable accuracy. The wiring diagram for such a system applied to a six-cylinder engine as manufactured by Delco-Remy and Hyatt, Limited, is shown in Fig. 30, the system being similar for both one and two lever constructions, except that in the latter there are two parallel parts of the primary circuit through the
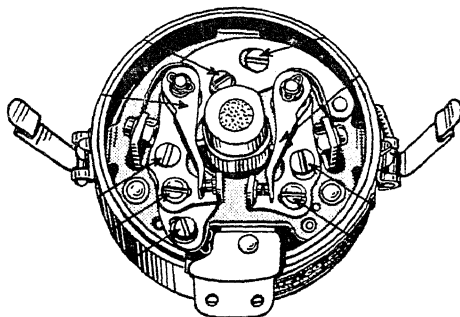
FIG. 33. VIEW OF DOUBLE BREAKER LEVERS

independent contact points. A vertical section through the apparatus itself is shown in Fig. 32. A pictorial view of the upper part of the housing with the cap removed showing the two contact-breaker levers is also shown in Fig. 33. The contact points are separated by the cams alternately, and in each case the breaking of the primary circuit induces a spark in the secondary circuit in the usual manner, this spark being led to the centre of the distributor and firing the cylinders in the order 1, 4, 2, 6, 3, 5. The condenser is connected across the contact points in the usual way to the primary circuit and to earth. A cap of the side outlet type is provided in which the leads enter a group of holes in the side usually on the left, each being connected to

its appropriate current collector by a pin which pierces right through the insulation. The automatic centrifugal advance device is arranged, as in the previous example, in the lower part of the base chamber.

Lucas Coil Ignition. This component is shown in Fig. 34. The automatic timing control of centrifugal

OIL RESERVOIR   AUTOMATIC TIMING
                                      CONTROL
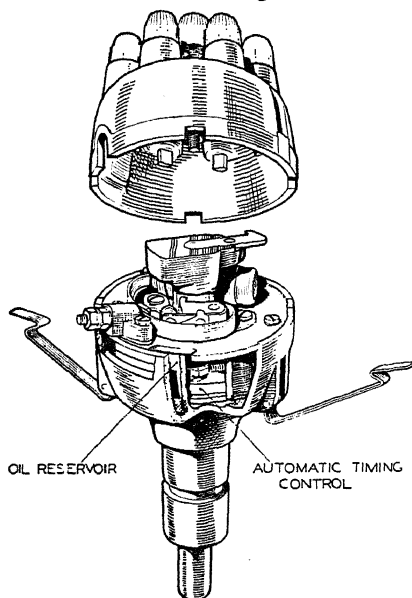
FIG. 34. LUCAS COIL IGNITION DISTRIBUTOR

character is located in the inner casing of the main body, the space between the inner casing and the outer casing forming an oil reservoir. This avoids the necessity for the use of the usual screw down greaser for effecting lubrication of the vertical spindle, a method which depends too much upon personal attention and memory to be regarded as a reliable way of dealing with this continually running member.

The contact-breaker is controlled by a long stainless steel spring and the lever itself is specially short and light in weight. It will be noted that the fibre heel engaging the cam and the movable contact point are very close together and are on the same side of the pivot, so that the moment of inertia of this component about its pivot is very small, and the tendency to "flinging" or leaving the cam at high speeds is reduced to a minimum.

The distributor arm is mounted on the top of the spindle and its metal end rotates just inside without touching the collecting pins shown on the inside of the cover.

The contact-breaker gap is adjusted by moving a plate carrying the fixed contact when the two securing screws are slackened. This adjustment does not disturb the bedding or engagement of the contacts themselves.

Installation. The location of the distributor unit is a matter of some importance from the point of view of accessibility, dryness, lubrication and length of high tension cables. The arrangement in which the distributor is above the engine cylinders at the upper end of a vertical shaft is preferable to that in which it is located alongside the engine either on or independently of the dynamo. In some designs the distributor shaft itself carries at its lower end a driving gear wheel, but arrangements in which the distributor spindle is driven through a dog clutch from some other spindle such as that on the oil pump, is to be preferred since the gears may be larger and freely lubricated without any risk of oil creeping along the shaft to the contact-breaker and other mechanism.

Cables should be as stout as possible without sharp bends and should be reasonably clear of hot metal, particularly exhaust manifolds and pipes. The high voltage current will spark across gaps of $\frac{1}{2}$ in. or even

more. Metallic clamps or supports should not be in direct contact with the thick rubber insulation of the cable but a layer of vulcanite, insulating tape or other insulator should be interposed. The difficulty is not direct failure of the cable insulation, but the possibility of a silent discharge over the outside of the cable, also known as a corona discharge which may produce ozone from the oxygen of the air in sufficient quantities to cause damage to the rubber.

The induction coil is usually completely waterproof, although its terminals are necessarily exposed. It should be mounted so that it cannot receive heat from the engine and a well-cooled fairly high position is generally best.

Contact-breakers. Reference has been made previously to the falling off of voltage at higher speeds with coil ignition systems. In addition to this, the speed at which the device will produce sparks is limited by the characteristics of the contact-breaker and the induction coil.

The systems which have been standardized for a number of years include a single arm contact-breaker co-operating with a coil of the external primary type, the combination being capable of operating up to engine speeds of about 5,500 r.p.m. but further advances beyond this speed have been made possible by modifications to the contact-breaker and coil.

Briefly, the production of ignition sparks at high speed depends upon the possibility of storing sufficient energy in the magnetic circuit of the coil during the short time available between sparks when the primary circuit is closed by the contact points. The time available is equal to the time interval between successive sparks, less the time that the points are opened by one of the cam peaks. The time of opening depends upon the movement of the contact-breaker as it follows

the cam, its weight and moment of inertia about its pivot and the allowable spring loading.

Unnecessarily fine adjustment of the contacts is avoided by working with a gap of not less than ·010 in. while ·015 in. has been widely used. The amount of the gap equals the distance the movable contact point lifts. The cam, as it rotates, strikes the fibre rubbing piece, giving the movable point almost instantaneously a definite velocity, and moving it through a distance of say ·015 in. before its velocity becomes zero. The contact spring reverses the velocity and forces the fibre rubbing piece to follow the cam until the contact points close. If the return part of the cam is parabolic, the spring will just be able, at a certain speed, to make the rubbing piece follow the cam without exerting any force upon it. This speed depends upon the strength of the spring and the inertia of the cam. At lower speeds there will be an excess of spring pressure so that the rubbing piece will press on the cam, but at higher speeds, the rubbing piece will be unable to follow the cam, that is, it will be flung clear, and the points will close later so that the time of opening of the points will be increased. The higher the speed, the longer will be the open period and the shorter the closed period.

As mentioned above, the duration of the closed period governs the possibility of producing sparks at all. At a speed not greatly in excess of the critical speed at which flinging occurs, no spark can be produced. If an attempt is made to increase the normal spring loading with the object of attaining a higher critical speed, the loading will be excessive in comparison with any result achieved, for not only is engine speed increased but the angular acceleration of the contact arm about its pivot is also increased. Consider an example of a six-cylinder engine in which the angle

between cam points is 60°, this being divided into 20° open and 40° closed. If the strength of the closing spring were increased and the cam made sharper so that the actual time of closing would be unaltered at an increase of speed of 25 per cent, the spring loading necessary to effect this would be about six times the original loading.

Assuming that the angle of close is 40° and that a speed of approximately 5,500 r.p.m. can be attained without flinging of the contact-breaker arm and with reasonable spring pressure such that excessive pressure on the working parts and undue wear are avoided, then the time of closing is very near to ·0027 second, or 2·7 milliseconds. A coil of usual design requires a time of 2 milliseconds if a satisfactory spark is to be produced. The limit of speed thus depends upon whether the time of closing of the contact points and the primary circuit is greater than the induction coil time.

The phenomena just described are shown graphically in Fig. 35, the distributor speed, which is half-engine speed being plotted horizontally while time in milliseconds is plotted vertically. Any ordinate of the upper curve is equal to the sum of the corresponding ordinates of the two lower curves. The middle curve showing contact closing time is of direct significance in relation to the horizontal line representing the time of 2 milliseconds required for the flow of current through the primary winding of the induction coil. As long as the closing time curve is above the horizontal coil line, sparking will take place. This curve is a rectangular hyperbola up to the distributor speed of 2,300 r.p.m. or engine speed of 4,600 r.p.m. at which flinging commences, after which it drops rapidly. The point where it crosses the horizontal coil line gives the limiting distributor speed of 2,750 r.p.m. Even if the coil were so improved that its time were reduced to

1·5 milliseconds, very little increase of speed could be obtained in view of the way in which the time curve drops sharply when flinging begins.
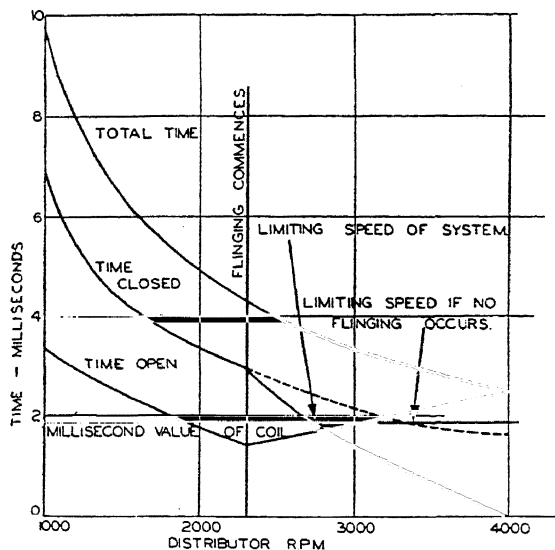
FIG. 35. CONTACT-BREAKER AND COIL CHARACTERISTICS SHOWING EFFECT OF CONTACT-BREAKER FLINGING ON LIMITING SPEED

(By courtesy of the Institution of Automobile Engineers)

Substantially higher speeds could, however, be attained if flinging could be deferred so that the time curve continued farther along the dotted line. This can be done by increase of spring pressure as mentioned above, but reduction of weight of the moving parts is more promising. It will be clear that the contact-breaker mechanism works under very severe conditions and attempts to raise the flinging limit might result in breakage or unreliability.

It is possible by providing the coil with an external

resistance to reduce the coil time to 1·5 milliseconds with a 12-volt system and this coupled with improvement in the contact-breaker mechanism would permit of the attainment of speeds in the neighbourhood of 8,000 r.p.m. in six-cylinder engines.

Speeds in excess of 8,000 r.p.m. or sustained speeds above 6,000 r.p.m. can be dealt with by the provision of two separate units carefully synchronized. Duplication of the contact-breaker arms allows of some small improvement since it is then possible to increase the angle of close of 40° referred to above up to 45° or even more, but it does not allow any appreciable reduction of spring load for a given speed.

Contact-breaker Points. In all ignition systems, the points have to stand a certain amount of sparking which it is impossible entirely to avoid, however well the condenser is designed and matched to the apparatus. The material most generally employed in this country for many years has been an alloy consisting of 75 per cent platinum and 25 per cent iridium. As both of these are classed as precious metals the cost of the contacts is very high, and a great deal of attention has been given to the provision of satisfactory substitutes. It has been found that tungsten points can be produced and will give very reliable service if used with battery ignition systems in which the current flows in one direction only. Alloys containing a large proportion of tungsten have also been employed.

Induction Coils. The ordinary induction coil is a transformer with characteristics adapting it for its special purpose but impairing to some extent its efficiency as a transformer. It may be described as an open core transformer; that is, the ends of the soft iron core are not connected by steel or iron to complete the path for the magnetic flux.

Magnetic circuits are used in many electrical

components, e.g. magnetos, dynamos, starters. In most cases the arrangement is always such that the magnetic circuit is closed by steel or iron, which facilitates changes and reversal of flux. For example in connection with the rotating armature type of magneto, the iron core of the rotor bridges the gap between the ends of the horse-shoe magnet, the only air gaps being those between the armature core and the pole pieces and these are made as narrow as possible to reduce the resistance to the completion of the magnetic circuit.

If magnetic leakage in a transformer or induction coil is neglected, the ratio of the numbers of turns on the primary and secondary windings gives the ratio between the electromotive forces in the two. The ratio between the current in each of the windings is the same, but inverse, so that

$$\frac{Np}{Ns} = \frac{Vp}{Vs} = \frac{Cs}{Cp}$$

The energy in each case is the same, being the product of Vp and Cs.

In small output transformers with closed magnetic circuits, the efficiency approaches 90 per cent, so that there is very little loss of energy and it remains cool. The loss of efficiency is due to several causes. Nearly the whole of the magnetic flux in the iron core passes through the windings, but the small amount which passes through the air spaces between the windings and known as the leakage flux results in some loss of potential difference in somewhat the same way as resistance in the windings cause a drop of voltage. To reduce these losses as far as possible, the coils are wound upon one another as closely as possible thus reducing the air spaces available for the leakage flux. Such transformers are described as close coupled. Air spaces cannot be wholly eliminated but the close

coupling in induction coils amounts to about 90 per cent.

The iron core accounts for two causes of leakage. First the eddy current losses which are reduced to a minimum by laminating. In the usual induction coil this is effected by using as the core a number of soft iron rods insulated by shellac, varnish, etc. In this way the eddy currents are limited by forcing them to travel in certain paths. The second cause of leakage is hysteresis, that is the tendency of iron when once magnetized to retain that magnetization and vice versa, so that a definite expenditure of energy is required to effect a change. This loss of energy like other losses appears as heat. Soft pure iron has less hysteresis than any other form of iron or of steel, with the exception of iron alloyed with a small percentage of silicon. Change of magnetism, that is, variation or renewal of flux through the iron core, takes place whenever the current through the windings changes or reverses.

In the induction coil or open core transformer, the iron magnetic circuit is so far from complete that the magnetic leakage is much greater, with consequent loss of energy and heating. In large transformers this heating would damage the windings, but in motor vehicle induction coils which are of very small size and power, the usual iron casing radiates the heat sufficiently.

The characteristics of the induction coil are, however, very different from the ordinary transformer. As a simple transformer of power it is very inefficient, but that is of small importance. As a means of obtaining an effective spark of very high voltage from a current of very low voltage within ·0001 second of the interruption of the primary circuit by the contact-breaker, it may be regarded as a very effective electrical device.

Experiment has determined that ignition will be

effected if the energy delivered at the plug points is at least ·001 joule with an E.M.F. in the neighbourhood of 5,000 volts. The energy produced by a magneto or a coil system is in excess of this, being in one case of the order of ·1 joule and in the other of ·03
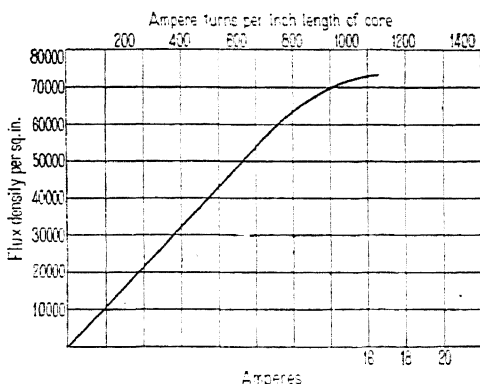

FIG. 36. CORES FOR INDUCTION COILS

joule ; although in the case of the magneto most of this energy is not available at starting when it is most required. Clearly a considerable excess is necessary in view of the possibilities of leakage of high tension current owing to the inherent deficiencies of sparking plugs and of the possibility of their being to some extent short circuited by oil, etc.

The bundle of soft iron rods constituting the core should have a ratio of length to diameter of about 10 to 1. The electro-magnetic properties of such a core are shown in Fig. 36. The direction of the curve at its upper end shows that the core is saturated when the flux density due to the primary winding is very little more than 70,000 lines of force per sq. in., and it is desirable to work to a density of about 60,000 for which about 800 ampere turns are required. The right combination of

turns and amperes must next be selected so that their product = 800. To consider extreme examples, if 800 turns of wire is considered, the length required must be of such a gauge that it will carry 1 ampere without undue heating. The self-induction effect due to the large number of turns will, however, be very high, and will retard the building up of the necessary flux density, so that the engine will misfire at high speeds even if the closed period of the contact points is 90 per cent of the highest possible. With such a long closed period the engines would be practically always certain to stop with the points in contact.

To take another extreme example, consider 100 turns, the length required being of such a gauge that it will carry 8 amperes. Owing to the low self induction resulting from the small number of turns, the flux would build up rapidly and extremely high speeds would be possible with the contacts closed for only 10 per cent of the possible period, and there would be very little likelihood of the engine stopping on contact unless very stiff. Should it do so, however, 8 amperes flowing for only a few minutes would probably cause excessive heating and consequent damage. Moreover, the platinum points would suffer through breaking such a relatively large current and a large condenser would be necessary.

In practice, a compromise is necessary, 400 turns, for example, on a 12-volt circuit forming the primary winding. The transformer ratio is usually of the order of 60, so that 400 primary turns would call for $60 \times 400 = 24,000$ secondary turns wound outside or inside the primary turns. This figure for the transformer ratio is only typical; it need not be so high for slow running engines, but, on the other hand, might have to be larger for fast running engines.

The voltage in the secondary being very high, the

amperage is correspondingly very small, being of the order of 10 milliamperes and wire of 40 S.W.G. diameter = ·0048 in. is large enough to carry the current. The secondary winding takes up much more room on the bobbin enclosing the core and it is usually longer than the primary winding.

The voltage difference between adjacent coils is small, so that only thin insulation is necessary and enamelled wire may be used. The drop between adjacent layers is, however, substantially greater, and further insulation, such as paper, must be provided.

If the voltage produced in the secondary is, say, 6,000, and the transformation ratio is 60, the momentary voltage in the primary when the contacts are separated will be about 100. These voltages call for adequate insulation for the condenser, especially in view of the fact that they may be doubled should a plug lead become detached.

The considerations affecting the co-operation of the coil with the contact-breaker have been referred to previously in connection with the limits of performance at high speeds. The resistance, inductance and time available for storing energy in the coil at high speed are all interconnected. At low speeds, the question of low battery voltage must be considered since the heavy current required by the starter motor to turn a cold, stiff engine may reduce the battery voltage by as much as 50 per cent. Proposals have been made to meet adverse starting conditions by the provision of a resistance in series with the primary, the resistance being short-circuited when starting. Also an additional primary winding in parallel with the usual one has been proposed for use only when starting, so as to lower the internal resistance and allow an increased flow of current.

The induction coil is a compromise between these high-speed and low-speed conditions, and simple rules

for its dimensions and proportions cannot be given. For example, the relation between primary and secondary volts cannot be stated simply in terms of the ratio between the primary and secondary turns. If the matter could be so simply stated, the ratio in the case of a 6-volt coil would be double that in a 12-volt coil. But in the Lucas coil referred to below, the ratio of the former is approximately 70 and of the latter 44.

Induction coils are usually made with the secondary winding inside and the primary outside, this arrangement having advantages over the older designs, in which the secondary was outside, as regards electrical functions, compactness and cooling. Some details of construction will now be given.
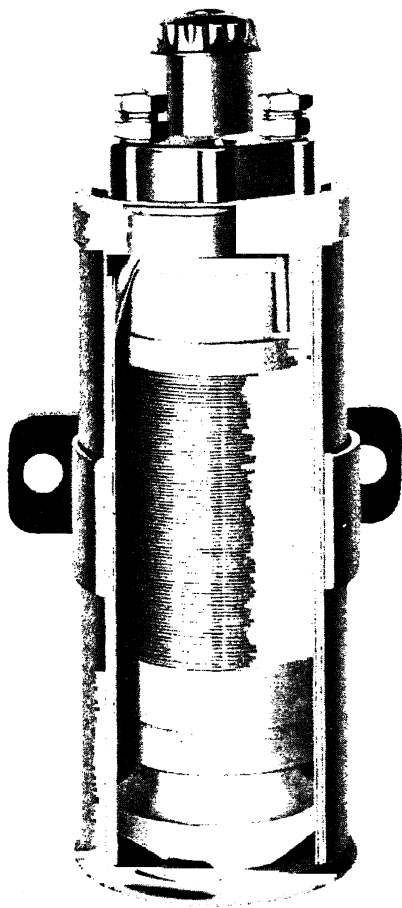
The secondary is wound directly on

FIG. 37. LUCAS IGNITION COIL
With case cut away to show primary winding

the iron core or on a shaped bobbin or tube of cardboard or other insulating material, into which the core is inserted later.

Lucas Ignition Coil. A sectional view of a coil made by Joseph Lucas, Ltd., is shown in Fig. 37. The secondary winding consists of many turns of very fine enamelled copper wire giving a total number of turns of the order of 16,000. The wire is wound on a former or bobbin and insulating layers of specially prepared paper are inserted between each layer of wire. The secondary winding is then impregnated with a wax material to prevent the ingress of moisture. After impregnation, further insulation is wrapped round the coil and the end of the primary winding is soldered to a flexible connection which is attached to the end of the secondary winding. The primary consists of three or four layers of a much thicker wire giving a total number of turns of about 350–400 for a 12-volt coil, and here again ample insulation is provided. The coil is finally housed in a metal case, which, after the assembly is completed, is filled with a bituminous material and sealed.

CONDENSERS

The condenser is a vital component of both magneto and battery ignition systems, and is usually connected across, that is in parallel with, the contact-breaker points. It may be regarded as a kind of electric spring or elastic container in which is stored up energy due to the inertia of the current flowing just before the contact points are separated. The hydraulic analogy referred to above is useful in this connection. Just as the air vessel cushions the flowing water when the valve is closed and absorbs pressure energy, thus preventing a violent and destructive rise of pressure, so the condenser, according to its capacity, stores up the electric energy which would

otherwise dissipate itself in sparks across the contact-breaker gap. The normal voltage (6 or 12) of the primary circuit is thereby raised momentarily, and it is this voltage which is multiplied by interaction with the secondary to provide the thousands of volts necessary for sparking.

The Leyden jar is one of the oldest forms of condenser. Tinfoil sheets on the inside and the outside of a glass jar form the positive and negative plates, while the glass forms the insulator or dielectric. A projecting brass rod is connected to the inner tinfoil for convenience of charging and discharging. If one plate is charged, a charge of opposite polarity is induced in the opposed plate, and the dielectric between them is put into a state of strain and may even be pierced and broken by a spark between the plates. Experiments which have been made suggest that the electric energy
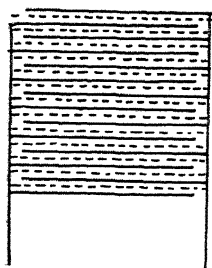

is actually in the strained medium and not in the plates. The capacity varies with the nature of the dielectric: ebonite and mica, for example, are much more effective than an air space. In a wireless set, air gaps are adequate for the small voltages of the aerial, whereas mica is required for the high tension currents in the reaction condenser.

Fig. 38. Diagram of Condenser

The condensers employed in ignition apparatus must be compact, and they are, therefore, constructed of a number of thin tinfoil plates separated by very thin sheets of mica, which are larger than the metal plates so as to overlap all round and prevent leakage. The plates are connected alternately to positive and negative terminals, and this forms in effect two large plates separated by the dielectric. Fig. 38 shows diagrammatically the construction of a condenser. The

capacity is proportional to the total area of the plates, and is inversely proportional to the distance between them. Hence the desirability of a large number of plates and a very thin dielectric. Mica is particularly effective in this respect.

The mica used has to be selected so as to be free from minute air bubbles or perforations. This mineral possesses extraordinary cleavage properties, as it can be divided into thin sheets of indefinitely minute thickness, ranging in the case of magneto condensers from ·001 in. to ·002 in. As an alternative to mica, specially prepared paper free from pin holes has been used.

The actual shape of the condenser varies greatly in practice, depending upon the location. In the rotating armature magneto it consists of flat plates shaped to fit in a recess at one end of the armature body. In coil ignition systems, it consists of a small self-contained detachable unit of cylindrical form. In the Scintilla rotating magnet magnetos it is of annular form and is arranged between the inner primary winding and the outer secondary winding.

IGNITION ADVANCE

The exact instant at which the spark is produced is determined with almost absolute accuracy by the breaking of the contact points. The interval between the two is so minute, owing to the speed at which electricity travels and the speed of electrical actions generally, that the crankshaft only turns through an angle of about $\frac{1}{2}°$ even at the highest engine speeds. If combustion were instantaneous, the ignition spark could then be timed to occur at the exact instant that the piston reaches the upper dead centre, the pressure of the hot gases would then instantaneously reach its highest value and would diminish as the piston moved downwards. The combustion, however, is by no means

instantaneous ; the period is small, being of the order of
·003 second, but varies greatly according to conditions ;
moreover, even if the period of combustion were invariable, the ignition would have to be advanced more at
high speeds than at low speeds to ensure attainment of
the maximum explosion pressure shortly after the top
dead centre. In practically all modern engines, provision is made for advancing or retarding the ignition
by an automatic advance control, which is generally
operated in accordance with the speed, but may
be partially regulated according to other principles.
With hand control the timing of the ignition is
very far from what is necessary to get the best
results, since adjustment of the ignition lever is often
not effected until the poor running of the engine calls
for further control ; that is, it is adjusted after it
has become necessary instead of at the proper time.
Automatic advance gives in general a closer approximation to correct ignition timing under most conditions
of running. It is usual to adjust the ignition advance
so that when fully retarded the spark occurs when the
crank is at the top dead centre. Backfire is impossible
when fully retarded, and the ignition point can be
advanced as required from the dead centre. Centrifugal methods of ignition advance have already been
described.

A certain amount of experimental work is necessary
generally before the most suitable ignition advance can
be determined for a reasonably wide range of speeds and
loads in any particular engine. In Fig. 39 are shown
the results of experiments made by Messrs. Delco-Remy
and Hyatt, Ltd., at quarter, half, and full load to determine the best ignition advance at speeds ranging from
about 800 to 3,000 r.p.m. to ensure the development of
the maximum power corresponding to each condition.
On the same diagram the straight line A B, which

coincides very closely with the full load curve, shows the relation between ignition advance and speed which can be obtained by a centrifugal advan e device. This device will thus give the correct advance when the throttle is fully open, and cuts in at a speed of about
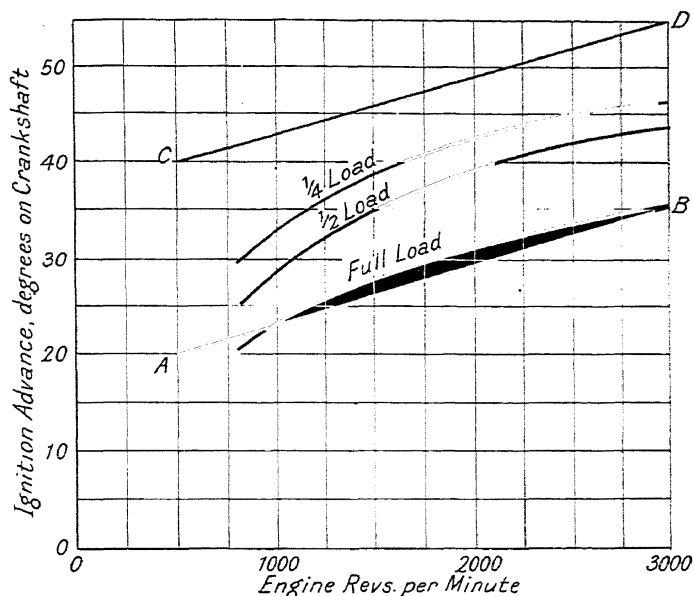

FIG. 39. RELATION BETWEEN SPEED AND IGNITION ADVANCE

500 r.p.m., below which the engine should never operate under load. For idle running a manually controlled device may be employed.

When running at light loads further advance still is necessary than is provided by the centrifugal device. It must be remembered in this connection that most engines run for a considerable proportion of their

running time with limited throttle opening. This additional advance up to the line $C\ D$ can be obtained, as required, by vacuum control dependent upon the vacuum in the induction pipe of the engine. It is well known that the vacuum in the induction pipe, that is the reduction of pressure below atmospheric pressure, varies considerably according to the throttle opening, the setting of which determines what fraction of the maximum power shall be developed at any particular speed. It will thus be evident that the combination of speed control with volume control enables a closer approximation to the exact requirements of the engine to be obtained.

Delco-Remy Automatic Advance. The centrifugal control may be arranged at the lower part of the casing, in which are located the cam and the contact breaker, this control being interposed between the upper end of the driving shaft and the cam so as to vary automatically the angular relationship between the two. The additional vacuum control is obtained by an angular movement imparted to the whole of the casing with its cap, as shown in Fig. 40. To the lower part of the base of the casing is clamped an arm a to which is pivoted at the point b a lever c, one end of the lever c being connected to the manual control and the other to a diaphragm d movable in the casing e, shown also in section in Fig. 41. The diaphragm, together with the connecting wire f, is forced to the left by a helical spring h so as to tend to retard the ignition. The left part of the casing is connected to the atmosphere and the right side has a connection g to the inlet pipe, close to the edge of the throttle valve, so that when the throttle valve is partly closed the suction of the engine is transmitted through the pipe d to the space on the right of the diaphragm, whereby the spring h is compressed, the wire f is pulled and the lever c is operated so as to
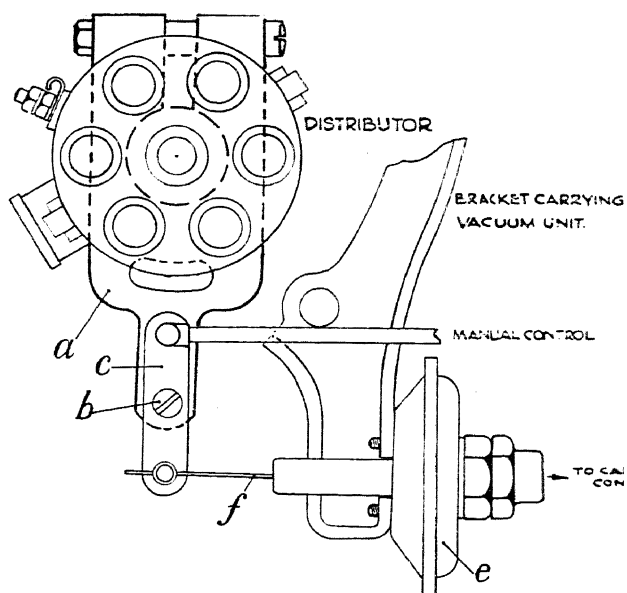
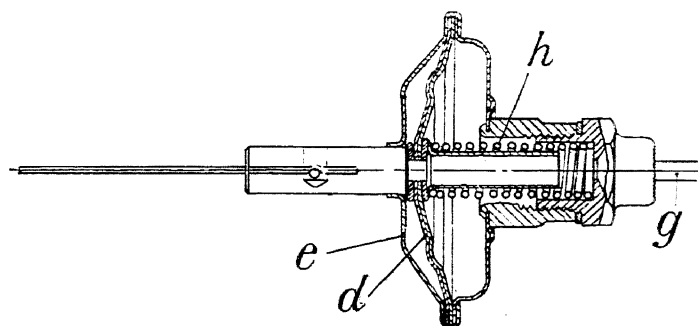FIG. 40. DELCO-REMY IGNITION ADVANCE. ENGINE VACUUM
CONTROL

FIG. 41. VACUUM CONTROL CASING WITH DIAPHRAGM

advance the ignition advance lever *a*. It will thus be seen that whenever the throttle is fully opened, the only effect of the vacuum control is to tend to retard the ignition fully : it is, however, then advanced by the
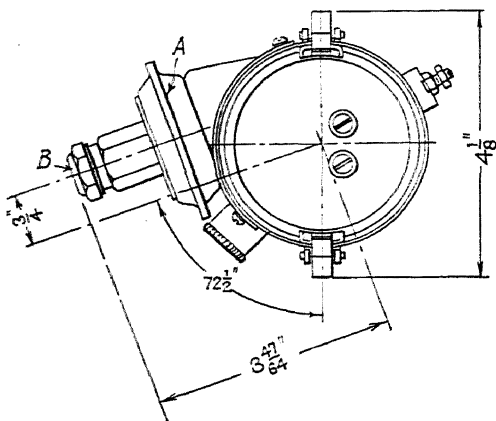

Fig. 42

centrifugal device. As soon, however, as there is any throttling of the engine, then the vacuum control brings about the additional advance required.

A very compact application of the principle is the Delco vacuumatic ignition distributor shown in the outline plan, Fig. 42, as used on a six-cylinder engine with firing order 1, 5, 3, 6, 2, 4. The suction tube is connected at *B* and leads to one side of the diaphragm in the casing *A*, which is very closely mounted on the body of the distributor. The diaphragm adjusts the circuit-breaker assembly (which includes in addition the condenser) about the axis of the camshaft in opposition to the return spring. The contact-breaker and condenser are mounted for this purpose on a disc

which is carried by steel balls to give free adjustment and avoid any possibility of sticking.

Lucas Automatic Advance. The Lucas coil distributor element shown in Fig. 43 contains the centri-
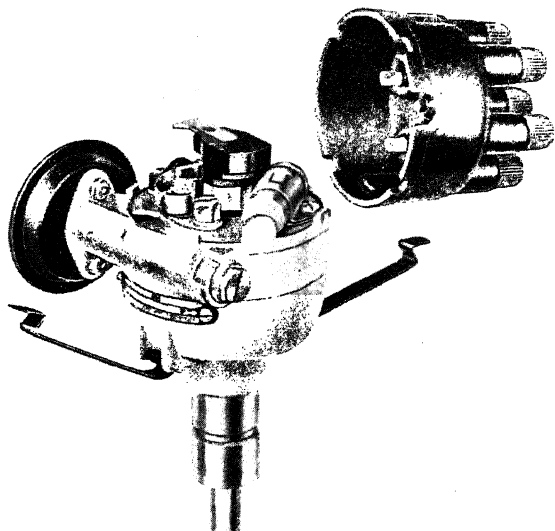

FIG. 43. LUCAS COIL IGNITION DISTRIBUTOR WITH IN-BUILT SUCTION TIMING CONTROL

fugal advance mechanism in the lower part of the casing. The suction advance mechanism is very closely associated with the casing so as to form a compact unit, the suction chamber being closed by a diaphragm subject on one side to engine suction in opposition to a spring. In addition a fine micrometer adjustment

enables the timing to be varied by the movement of a knurled knob, or, as shown, by a screw having a hexagon head and screw-driver slot. The range of adjustment provided is $8°$ retard and $2°$ advance, and it is intended that the distributor should normally be set by the maker of the engine so that the reading on the scale is $0°$. This gives the owner of the vehicle an opportunity of altering the timing in accordance with alterations in the engine conditions such as different grades of fuel, condition of the engine as regards carbonization, or other factors which may affect its performance.

The centrifugal device consists of mechanism which is adapted to alter the relative angular relationship of the lowermost driving shaft and the upper shaft carrying the cam and the distributor arm. The vacuum control also affects the advance by rotating forward or backward, according to the suction of the engine, the disc carrying the contact-breaker, condenser, and associated parts, thus adjusting this disc relatively to the casing.

Ford Automatic Advance. A method of modifying the speed and ignition advance curve given by the centrifugal mechanism in a special manner has been adopted by the Ford Motor Co. in connection with their V8-cylinder engines. A view of the contact-breaker mechanism is shown in Fig. 44 together with the vacuum mechanism. Within the main body is secured the ignition advance housing, enclosing the centrifugal advance mechanism and carrying the breaker plate on which is mounted the contact-breaker arms; these parts do not move. The distributor shaft rotates the cam through centrifugal mechanism, the weights increasing the angular advance of the cam relatively to the distributor shaft as speed increases in opposition to the springs which retard it when the speed falls. The centrifugal mechanism is

set to give advance at the lower speeds suitable for
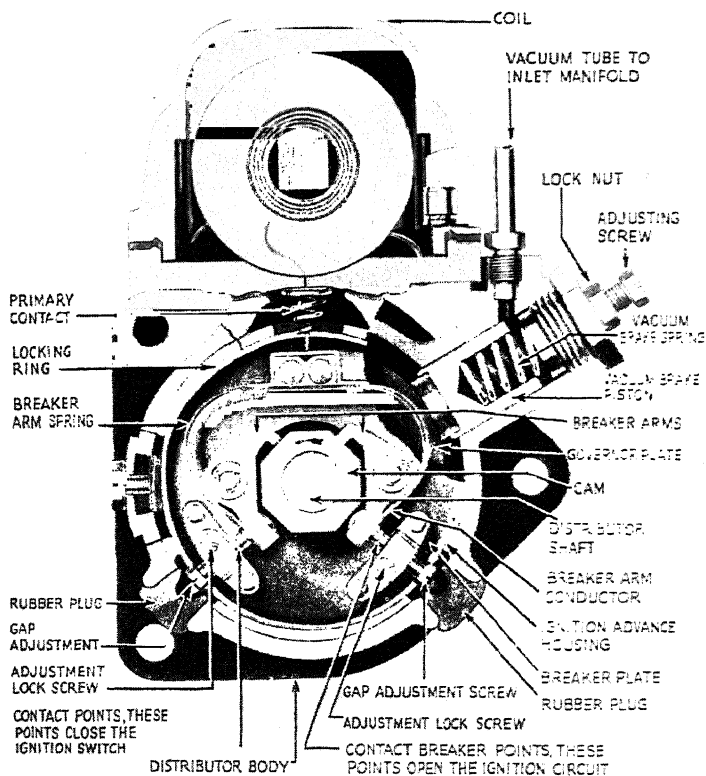reduced power. Some retardation is therefore neces-

FIG. 44. CONTACT BREAKER AND SUCTION RETARD

sary when the engine is accelerated to give maximum
torque at the lower speeds. This is effected by the
vacuum brake piston which is forced by the vacuum

brake spring into engagement with the edge of the rotating governor plate connected to the cam. When the engine is running light with a small throttle spring, the high suction in the inlet manifold opposes the vacuum brake spring so that the brake exerts very little force on the governor plates; but when the throttle i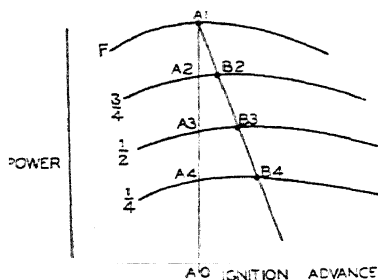s opened to give strong acceleration, the decreased vacuum in the manifold allows the spring to apply the brake to the governor plate, thus retarding the ignition.

FIG. 45. ENGINE POWER WITH VARIOUS THROTTLE OPENINGS

Throttle Valve Connections. We have seen that the suction on the engine side of the throttle valve increases as the throttle valve is closed, and this suction can be utilized to increase the advance at small throttle openings and low speeds so as to correct the ordinary centrifugal advance mechanism which depends solely upon speed. It is desirable that at very low idling speeds less advance should be given and this modification may be obtained by careful positioning of the point of connection of the suction unit to the induction pipe relatively to the edge of the throttle valve.

To consider this question and also somewhat further the general question of advance, reference is made to Fig. 45 as supplied by Joseph Lucas, Ltd. The diagram relates to an engine running at a certain speed and the curves and the power correspond to ignition advance for four throttle openings, namely, full, three-quarters, half, and one-quarter. The ordinary centrifugal

mechanism gives a definite advance which is constant for the one speed for which the diagram is drawn, and is represented by the vertical line $A0$, $A1$. The point $A1$ for full throttle is on the peak of the power curve, but the points $A2$, $A3$, and $A4$ for lower power outputs are in such positions that the maximum power cannot be developed without some modification of the angle of advance. The suction control superimposed on the centrifugal control gives an advance along the lines $A1$, $B4$, and the several points $B2$, $B3$, $B4$ are practically on the peaks of the several curves. At idling speeds, however, it is desirable that the suction of the engine should not have any effect, since at these low speeds the engine should not be developing any appreciable power. This may be effected by drilling the hole connected to the vacuum unit in the location indicated on the left-hand side of Fig. 46 in which the throttle valve is shown in its closed position. For nearly closed positions of the throttle, no suction is exerted on the unit since the hole is sufficiently far on the open or carburettor side of the throttle valve. As the throttle opens, the suction of the engine gradually takes effect on the connection to the vacuum element as shown in the middle view, Fig. 46, until a maximum advance due to suction is given corresponding to the point $B4$ in Fig. 45. Further opening of the throttle results in further diminution of the suction so that the advance follows the line passing through the points $B3$, $B2$, $A1$ on Fig. 45.

During accelerating periods at middle and lower speeds, the amount of throttle opening is such that the vacuum in the induction pipe is small and the ignition advance is then only that due to the centrifugal mechanism. This meets engine requirements since an engine running at any given speed requires less advance at full power than at $\frac{1}{2}$ or $\frac{1}{4}$ power.

One disadvantage on some engines of this characteristic of substantial retardation at low speeds to give good slow running of the engine is the possibility that there may be difficulty in starting a cold engine unless a fair degree of advance is given, and the engine may be sluggish until it is well warmed up. The advance necessary to avoid this may readily be given when
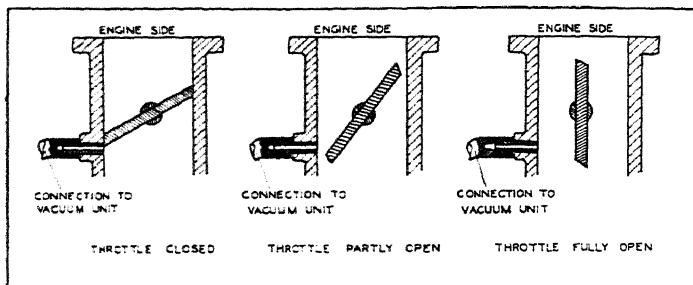

FIG. 46. SUCTION ADVANCE CONNECTION TO CARBURETTOR

hand control gear is fitted. Unless, however, provision is made to ensure substantial retardation, there is the possibility that the engine may backfire and even run reversely. It is possible so to adjust the ignition timing and control that backfiring is impossible, even at the cost of sluggish starting and running when cold, and in some countries such safety precautions are enforced legally. The carburettor and quality of the fuel are important factors in this connection.

Ignition Switch. This, besides stopping the engine, prevents the battery being discharged by the current through the primary windings when the engine has stopped. Should the switch be closed with the engine stopped, a red lamp on the instrument panel gives a warning. This lamp is then supplied by the battery, but as soon as the dynamo voltage equals that of the

battery, no current flows through the lamp. If the warning bulb burns out, the operation of the ignition system is not affected.

SPARKING PLUGS

The sparking plug, although so small and apparently so simple a component, works under the most difficult conditions and performs a vital function. The voltage of the current supplied is so high as to cause difficulties in the matter of insulation, while the high temperatures to which it is subjected and the corrosive character of the contents of the combustion chamber call for considerable knowledge and skill in design and construction.

A satisfactory plug for any particular kind of engine should possess the following characteristics. Exceedingly high resistance to leakage of current; continued maintenance of the proper spark gap under adverse conditions; resistance to corrosion; gas tightness; long life; sufficient "reach" into the combustion chamber.

Reference has already been made to the production of sparks under pressure, and a few other aspects of plug construction will now be considered.

Electric leakage may be due to defective insulation or to carbon or dirt leading to surface leakage. None of the materials classed as insulators are completely effective. They may be described as possessing an exceedingly high resistance, which in sparking plugs may decrease under certain conditions. One of the most widely used materials is porcelain, which consists of compounds derived from aluminium and silicon; the oxides of these metals, mainly alumina and silica, form the basis of clay and sand respectively. The insulator is glazed, that is, covered with a kind of class fused on, thus avoiding porosity and facilitating gleaning. Leakage may take place along a fine film

of oil on the surface of the insulation or on any part, such as the distributor moulding in contact with the high tension circuit.

A great deal of research has been carried out in connection with this important matter of sparking plug insulators in view of the severe conditions and exacting requirements, and special natural and manufactured substances have been discovered possessing very high electrical resistance, improved heat conductivity and greater mechanical strength.

Mica, in view of its finely laminated structure, presents certain difficulties in manufacture but has peculiar advantages. It has very good dielectric properties and is quite unaffected by the gases in the combustion chamber or by heat, though care must always be taken that finely divided particles of carbon cannot penetrate far between the layers.

The insulator must be kept above the temperature at which carbon can form on it, since carbon is a conductor of electricity. At the same time the temperature must not rise high enough to cause pre-ignition and general deterioration. Actual temperature when running depends both upon the construction of the plug and the kind of engine. A high speed engine runs hotter than a commercial vehicle engine and will require a different design of plug, while in either case the plug used must function over a wide range of temperature.

Too high a temperature of the electrodes, which are often made of nickel, leads to rapid corrosion, principally by the action of sulphur. The rate of corrosion increases rapidly above about $500°$ C. Fig. 47 gives some indication of how temperature varies with engine speed. The curves K-9 (14 mm. diameter of thread) and G-9 (18 mm.) relate to plugs made by the A.C.-Sphinx Sparking Plug Company Limited.

A wider range of spark gap is possible (for example ·010 to ·030 in.) if plugs and ignition are in perfect condition, but in practice a gap of the order of ·018 in. is used, since too small a gap leads to short circuiting by oil or carbon and too large a gap to misfiring.
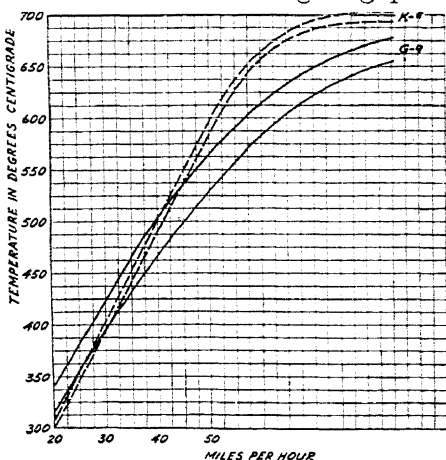

FIG. 47. TEMPERATURES OF DIFFERENT TYPES OF A.C. SPARKING PLUGS
In cylinder Nos. 1, 4 and 8 of a car driven at constant speeds from 20 to 80 m.p.h. on a level road

The question of spark gaps is, however, very indefinite since engine as well as plug characteristics vary greatly. Also larger gaps are in general permissible with coil ignition than with magnetos, while the difference is even greater when the so-called high voltage coils are used, some of which may give up to 25,000 volts. Voltages in ordinary use are of the order of 5,000 to 10,000 and are generally adequate. With some magnetos plug gaps of ·012 to ·016 in. are recommended, while with coil ignition systems some plug makers recommend gaps of from ·012 to ·020 in. for high compression engines and ·024 to ·032 in. for ordinary compressions.

The position of the points in the cylinder may be of the greatest importance, a difference of $\frac{1}{4}$ in. in or out often seriously affecting the engine performance.

The details of plug construction vary greatly and, moreover, as indicated above, a plug must be suitable for the engine on which it is used. This means primarily its self-cooling characteristics.
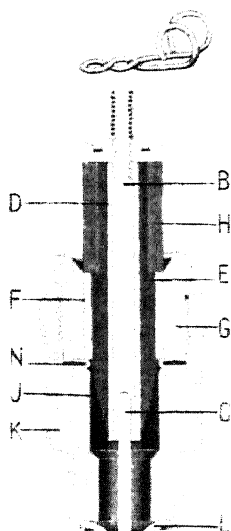
In the K.L.G. plug shown in section in Fig. 48, the central steel electrode B, having a heat-resisting alloy firing point C, is in close contact with a copper sleeve D wrapped round with sheets of mica E, the internal surface of which is stepped as at J to provide high resistance to the deposition of oil and carbon. A sleeve F is contracted on to the mica wrappings E. The external insulating surface is formed by mica washers H clamped down by the end nut. The earthing disk L is formed with three points which give a long life before adjustment becomes necessary. Gas tightness is obtained by the copper-asbestos washer N clamped in the steel rust-proof body K by the gland nut G.

Three points on the earthing disc L distribute the wear and lengthen the running periods before adjustment of the gaps becomes necessary.

Fig. 48. K.L.G. Sparking Plug

A similar design of K.L.G. plug shown in Fig. 49 has a central electrode with a firing point of fine platinum wire fitted therein. Platinum is one of the best non-corroding heat-resisting metals known, but is very expensive. The platinum firing point is securely caulked into the end of the electrode. The earth
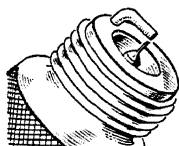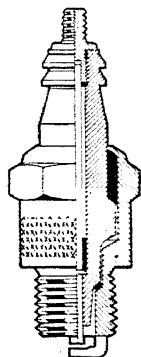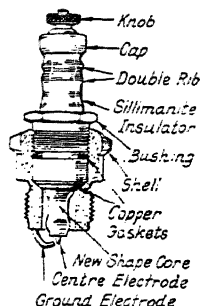

FIG. 49

FIG. 50. CHAMPION SPARKING PLUG

FIG. 51

electrode of large diameter provides a large sparking area for the fine platinum point.

In Fig. 50 is shown a part section of a Champion sparking plug of the type which cannot be taken to pieces since the metal of the body at the outer end is spun over to grip the insulator and the packing rings and ensure gas tightness. The provision for ensuring gas tightness between the central electrode and the insulator should be noted. With the arrangement of electrode shown the spark gap can be readily adjusted by bending the outer electrode towards the tip of the central electrode. There is no temptation in this case to bend the central electrode sideways, thereby breaking or at least seriously damaging the end of the insulator.

Another design of Champion sparking plug is shown

in Fig. 51. this being of the demountable type with a
screwed gland or bushing and an insulator of special
shape and material. These plugs are graded in accord-
ance with the different lengths of insulator projecting
into the firing chamber so as to control the rate of
flow of heat from the spark gap to the body of the
plug which is cooled by air and the cooling water.
The electrodes must be hot enough to burn oil and
other residues and prevent the formation of soot which
would ultimately short circuit the electrodes to the
body of the plug. These conditions correspond to
frequent stops and much engine idling and call for a
plug of relatively poor conductivity. On the other
hand, the electrodes must not be overheated and incan-
descent since pre-ignition may result. These conditions
correspond to high speed and hard pulling and call
for a higher degree of conductivity of the central
electrode and the inner end of the insulator. It is
always possible to find a plug which will cover the
usual range of conditions for any given engine, whereas
a different plug might be required for a hotter engine
working with higher compression or under conditions
tending to higher temperature. Plugs having porce-
lain-like insulation can in general be cleaned by a
sand blast without risk of damage, whereas mica plugs
cannot be treated in this way.

Joseph Lucas, Ltd. have carried out tests on engines
running under various conditions to deal with claims
which have been made that substantial economy of
petrol consumption follows from wide spark plug gaps
of for example ·030 to ·040 in.

They have found that an improvement not greater
than 5 per cent can be obtained with small throttle
openings, while with throttle openings giving half
power or more no improvement can be detected. With
small throttle openings, the mixture in all the cylinders

is not homogeneous but contains a large proportion of unburnt gases and the greater spark volume from wide gap plugs increases the probability of some ignitable parts of the mixture being in the path of the spark. The greater spark volume also reduces the necessity for the slightly greater ignition advance required at small throttle openings. Wide spark gaps have thus to some extent the same correcting action on centrifugal advance mechanism as the engine vacuum control arrangements described earlier.

To obtain maximum benefit from wide spark gaps, the design of the carburettor, the induction pipe, and the manifold, must be such as to secure uniform distribution of the mixture in all the cylinders to avoid some running rich while others are starved. This is difficult with a single carburettor and a number of cylinders. Six-cylinder engines are notoriously not so economical as four-cylinder engines of the same capacity other things being unaltered. Hence two or even three synchronized carburettors are sometimes fitted. If, however, the effect of wide gaps results in the firing of excessively lean mixtures, burnt exhaust valves and other troubles may result. This is broadly due to the fact that weak mixtures burn more slowly and the exhaust valves are exposed for a longer time to flaming gases during the exhaust period.

Wide gaps may call for the use of high voltage coils on high compression engines, although with most engines the usual coil ignition systems are adequate under normal conditions to furnish the higher voltages required.

More frequent spark gap adjustment is necessary to correct the increasing size of gap resulting from wear. Also the higher voltages impose a greater strain on the insulation of the sparking plugs and on the high tension cables. Misfiring may also be caused by the

spark flashing over the surface of the insulation of the plug due to the presence of a film of moisture or oil forming a leakage path from the central electrode to the body of the plug.

DYNAMOS

The dynamo is the sole source of electrical energy for all purposes, with the exception of the ignition in those vehicles where a magneto is fitted. The amount of power expended in this way on the larger passenger vehicles is considerable, being in some cases as much as 6 horse-power.

The types of dynamo available for use are somewhat limited by reason of the comparatively low voltages (6, 12 or 24 volts) of the charging and lighting systems, and the fact that the use of an accumulator calls for direct current. Further, the wide range of speed, the necessity for practically constant voltage, and the wide variations in the demand for current call for special design and special methods of control. The dynamo can only be permitted to "cut in" when the speed is high enough to ensure a voltage at least equal to that of the accumulator, so as to avoid discharge of the accumulator through the dynamo; and provision must be made automatically to limit the output and avoid overcharging.

Motor vehicle dynamos are all very similar in appearance, and casual inspection fails to disclose their essential characteristics or the exact arrangement of the multitude of windings. Their essential features can, however, be shown diagrammatically and their method of working examined.

Generating Principles. All electric generators develop, in the first place, alternating current. In the magneto, the direction of flow is of no importance, but in the

dynamo the alternating current must be rectified or converted into direct current by a commutator.

The current generating action in a dynamo is based, as in the magneto, upon the movement of a conductor across magnetic lines of force connecting north and south magnetic poles. The electromotive force (E.M.F.) expressed in volts depends upon the number of lines of force cut per second in each circuit through the armature. The voltage is stabilized by the battery and
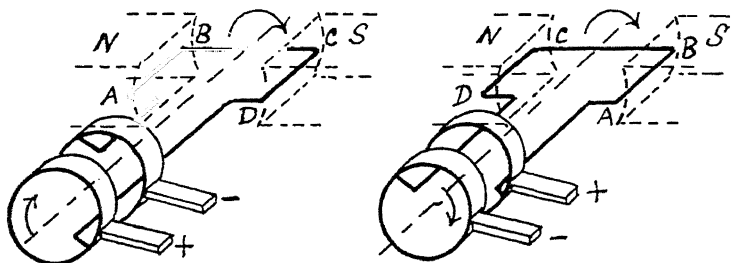

Fig. 52

the current then depends upon the total resistance in the circuit.

In the simple alternating circuit shown in Fig. 52, an armature element consisting of a U-shaped wire with its end attached to collector rings is rotated with the rings in a clockwise direction in the magnetic field. An electric current is produced in the wire when it cuts the lines of force. This current is conducted through the collector rings and the carbon brushes, and led through the circuit in which it is to be utilized, a small fraction, of the order of one-tenth, being employed to energize the field magnets.

A current is generated in the direction A, B, C, D, as shown on the left of Fig. 52, when the loop is turning in a clockwise direction, and cutting the lines of force stretching between the poles. This direction of flow

determines the polarity of the two collector rings and the carbon brushes. When the wire has rotated through 180 degrees to the position shown on the right, the current flows in the direction D, C, B, A, and the polarity of the collector rings and brushes is reversed. After half a revolution the current will again be reversed and will flow as before.

The Commutator. The alternating current in the windings is rectified or converted to direct current by
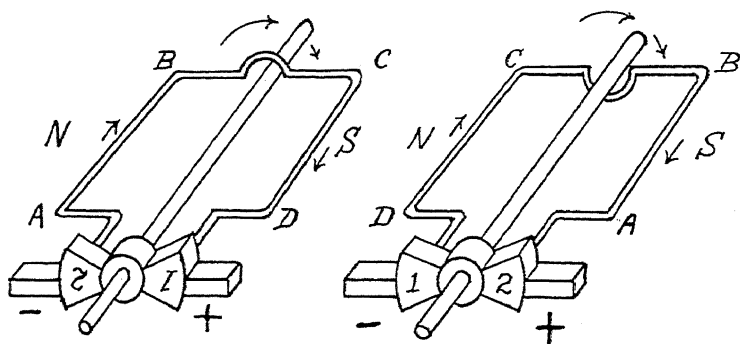

FIG. 53

means of a commutator. The collector rings are split into sectors or wedges insulated from one another by thin mica sheets and built up into the circular commutator, two such sectors with the armature winding to which they are connected being shown in Fig. 53. The sectors 1, 2, make contact with the positive and negative carbon brushes when the winding is approximately horizontal. When the wire is in the position shown on the left, and rotating in a clockwise direction, current will flow in the direction A, B, C, D, so that the left sector is negative, and the right positive. After rotation through 180 degrees, the current flows in the direc-

tion D, C, B, A, as shown on the right. The left sector is still negative, and the right still positive. The direction of flow through the brushes to the external circuit is therefore always in the same direction.
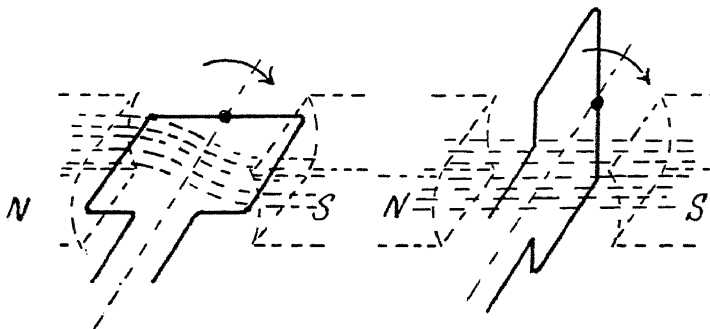

FIG. 54

Instead of the carbon brushes making continuous contact with a single collector ring, as shown in Fig. 52, and so collecting alternating current, they are thus in contact with the sectors alternately so that the current
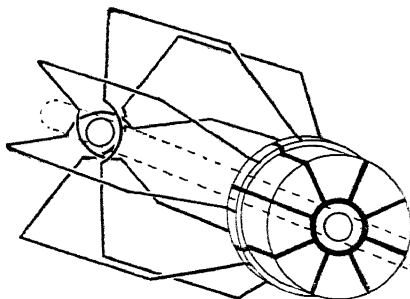

FIG. 55

is always direct. Such a simple two-piece commutator would produce a pulsating electromotive force, the E.M.F. being greatest when the wires, as shown on the

left of Fig. 54, are horizontal, and cutting the lines of force most rapidly, and weakest when they are vertical. By using a number of pairs of sectors each with their U-shaped wire, built up to form a circular commutator, the pulsating direct character of the direct current is greatly reduced, and it becomes more nearly continuous. The greater the number of windings, the more current will be generated, and the more continuous its character. Fig. 55 shows pictorially four wires each with its pair of sectors built up to form an armature known as an open circuit armature, since the circuit through each winding is only closed during the limited period when its sectors make contact with the brushes : that is, current is only generated in each winding when it is approximately in the plane of the field poles. This arrangement limits output and is not effective in practice, and modifications known as closed circuit systems are used, so as to ensure that all the armature windings are always in operation conveying current to the brushes, although their effectiveness varies during each revolution.

FIG. 56

Armatures. A closed circuit or series-parallel armature is shown diagrammatically in Fig. 56 with eight insulated commutator sect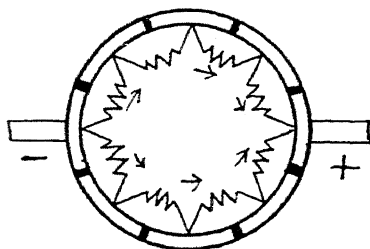ors, as in Fig. 55. The two ends of each wire are, however, connected to adjacent sectors instead of diametrically opposite ones, and eight instead of four windings are provided, so that each sector has one end from each of two adjacent windings connected to it. The wires are arranged as before with the two effective parts of each wire more or less diametrically

opposite so that the current in the two parts is not opposed; but the ends of the wires are led in opposite directions round the armature so that they may be connected to adjacent sectors. Part of the current flowing through the armature from one brush to the other passes through the windings on one side, and the remainder through those on the other side, these two sections of the circuit thus being in parallel, although the several armature windings in each section are in series.

To give a general idea of this arrangement, a pictorial view of Fig. 56 has been constructed and is shown in Fig. 57, but with only four sectors and four windings for the sake of simplicity. In practice a much larger number of sectors and windings is employed, but the principle of operation is the same.

In actual constructions, the number of windings is very much greater, and they are built up so as to form a very

Fig. 57

compact element, in conjunction with the core, which consists of a number of thin iron stampings separated by very thin paper or varnish to prevent eddy currents. In a slotted armature core the windings are laid in recesses in the periphery (Fig. 58) and held by plates and wedges to resist centrifugal force. The plates are clamped together, as, for example, by end plates and bolts, and are keyed to the armature shaft.
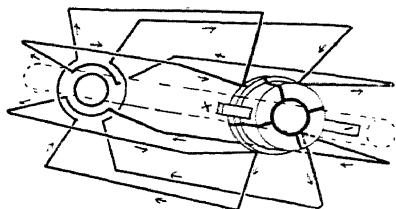
A conventional diagram of an armature winding is shown in Fig. 59. There are eleven sectors on the

commutator lettered *a–k*, and each sector is connected to the ends of two windings. In practice there would be a substantially larger number, but the method is identical. The general direction of each wire on the diagram corresponds closely with its arrangement on the armature. Consider, for example, the wires connected to the sector *g*. The wire directed towards the right passes
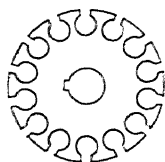

FIG. 58
ARMATURE
PLATE

through the magnetic field due to a *S* pole and, after being bent round through about 90° at the end of the armature remote from the commutator, it returns through the magnetic field due to the adjacent *N* pole to the commutator sector *a*. As the armature rotates, the two parts of each winding will always be seen to be moving in fields of opposite polarity (except when in the substantially neutral area between fields) so that the current generated flows in the same direction.

The winding also connected to the sector *g* but directed towards the left passes to the sector *b* in a similar way.

Consider now in detail exactly what is happening as the armature with commutator sectors is driven so that its wires traverse the stationary fields while the sectors rub over the fixed brushes. During the interval (of the order of ·0003 second) that the brushes are in contact with the sectors *b*, *e*, the current flows from the negative brush and the sector *e* towards the right, through one winding to the sector *j*, thence in a similar way through other windings to the sectors *d*, *i*, *c*, and *h*, until it reaches the sector *b* and emerges through the positive brush. Simultaneously current flows from sector *e* towards the left through other windings connected to the sectors *k*, *f*, *a*, and *g* until it emerges through the sector *b*. The two brushes touching sectors
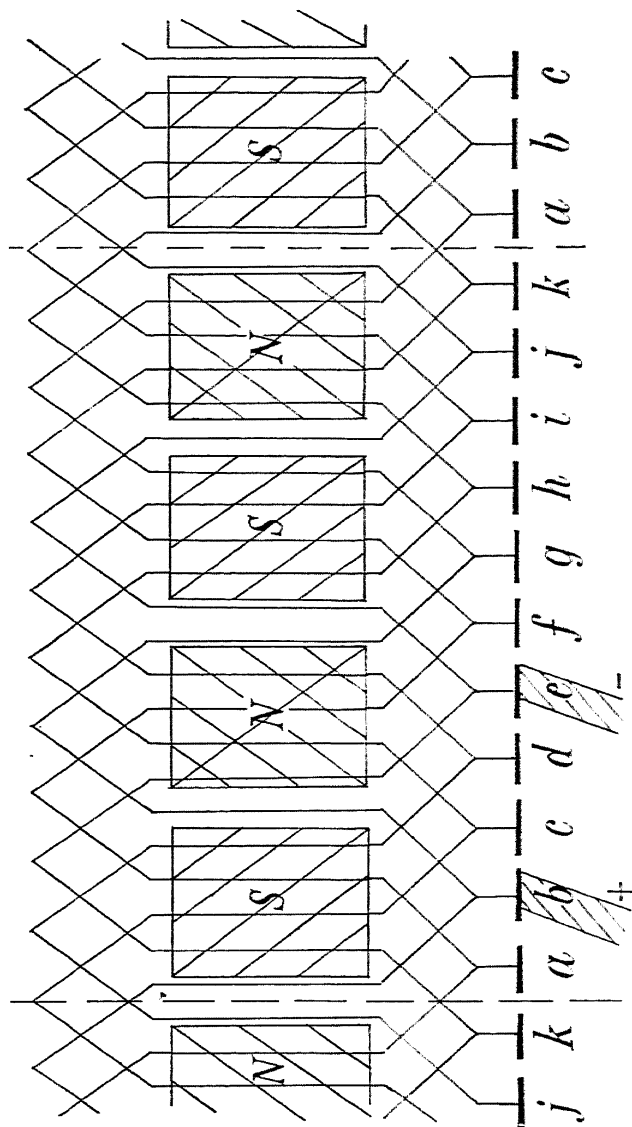
Fig. 59. Armature Windings

ϵ and b are thus connected by two parallel circuits, one circuit including six windings in series and the other five, so that current is being generated by every wire in the armature simultaneously. The action may be represented thus—

$$b \left\{ \begin{matrix} h-c-i-d-j \\ g-a-f-k \end{matrix} \right\} \epsilon$$

The next instant the armature has moved on, so that sectors d and a are in contact with the brushes, and a similar pair of parallel circuits is established through all the windings. In this case the arrangement of the windings in the two parallel circuits is as follows—

$$a \left\{ \begin{matrix} g-b-h-c-i \\ f-k-e-j \end{matrix} \right\} d$$

A similar result is obtained in all positions so that the brushes are always in circuit with all the windings in all positions, and any wire traversing any part of the field contributes its share to the output.

This method is known as wave winding, since the winding proceeds in a zigzag or wavy line round the periphery of the armature. The terms "series" or "two circuit" are also used. In order that all the conductors may be included, the number of sectors and windings must be odd. For dynamos of the dimensions suitable for motor vehicles, four poles are usually most convenient, but it is a characteristic of this method that only two brushes are required whatever may be the number of poles.

Another arrangement of the armature conductors known as lap winding is also employed.

The E.M.F. induced in the armature is given by the expression—

$$E = \frac{p}{c} NZ \, n \quad 10^{-\circ} \text{ volts}$$

where p = number of poles.

      c = number of parallel circuits through the armature; that is, two for wave windings.

      N = flux per pole.

      Z = number of armature conductors in series.

      n = revolutions per second.

All the symbols in the equation except N and n are dependent upon the construction and cannot be varied.
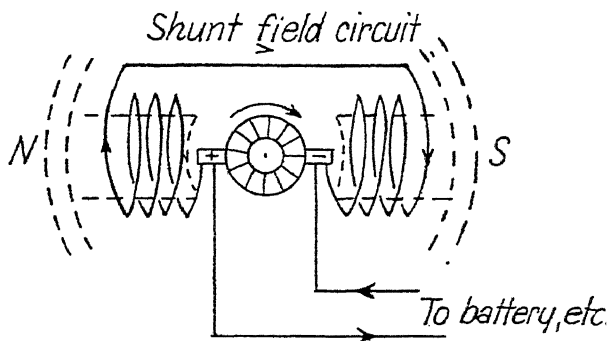

FIG. 60. SHUNT-WOUND DYNAMO

Also n necessarily varies within very wide limits, but the voltage cannot possibly be allowed to vary in a similar way. It is therefore essential that the field strength N should be controlled inversely as the speed changes so as to ensure substantially constant voltage.

In a series dynamo, the armature field coils and external circuit are all connected in series, the field winding consisting of a comparatively few turns of heavy gauge wire to carry the whole current without excessive heating. The load and voltage vary greatly, and the system is quite unsuited for motor vehicle dynamos.

Starter motors are, however, always series wound, as the system is very adaptable for great variations of speed and power.

Dynamos used in lighting systems are usually shunt wound, as this method is best adapted for the attainment of approximately constant voltage with varying
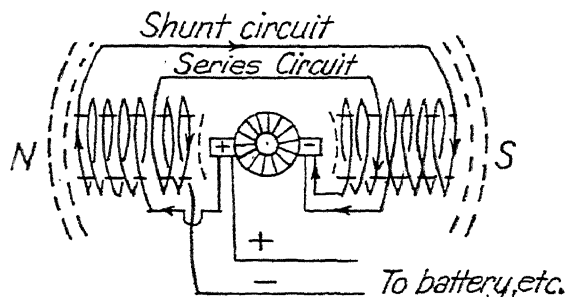

Fig. 61. Compound-wound Dynamo

speed and for current regulation. The field current is about one-fifth of the total output and the output of the dynamo is always controlled by regulation of the field circuit.

The field windings in the diagram, Fig. 60, form a shunt circuit from the main carbon brushes, the armature and the field windings being thus in parallel. The direction of the winding is such as to produce opposite polarity in the two field poles. Many turns of fine wire are used, giving a high resistance so that only a small current is taken, but the large number of turns gives sufficient excitation.

A simple shunt dynamo gives a decreasing voltage as the load increases, and some further control is sometimes necessary as by the addition of a series winding, when it becomes a compound wound machine. In this system, shown diagrammatically in Fig. 61,

the shunt and series windings are opposed. If both windings produced the same magnetic effect, they would neutralize one another, but the two are in fact so calculated as to maintain substantially uniform voltage over a considerable range of speed. The compound dynamo may be looked upon as a shunt machine having a series winding to compensate for the falling voltage. It is, however, little used on motor vehicles.

Lucas Dynamo. The standard dynamo has a cylindrical steel casing and is usually classified according to its diameter. Fig. 62 shows a dismantled dynamo made by Joseph Lucas, Ltd., alternative end brackets, carrying the brushes, being included, one end bracket having two brushes and being intended for use with a constant voltage controller, while the other has, in addition, a third brush when the dynamo functions as a third-brush machine. The armature runs in a ball bearing at the driving end and in a porous bronze bush at the commutator end. Both end brackets are spigoted and positioned by registering lugs on the turned ends of the casing. Through fixing bolts pass lengthwise between the pole pieces which are secured by screws in the casing. The mica insulation must be undercut to a depth of $\frac{1}{32}$ in. below the surface of the commutator segments.

Scintilla Dynamo. The dynamo of the four-pole type is shown in section in Fig. 63. The pole pieces 3 are secured inside the cylindrical shell 10 by screws, and the extension of their ends in both directions circumferentially serves both to obtain close co-operation electromagnetically with the armature, and to hold the windings in position. The drawing shows how the windings of the armature 2 extend from the insulated sectors of the commutator 5 through the slots in the laminated core, and are then led back to the commutator through other slots. The carbon brushes

FIXING BOLTS

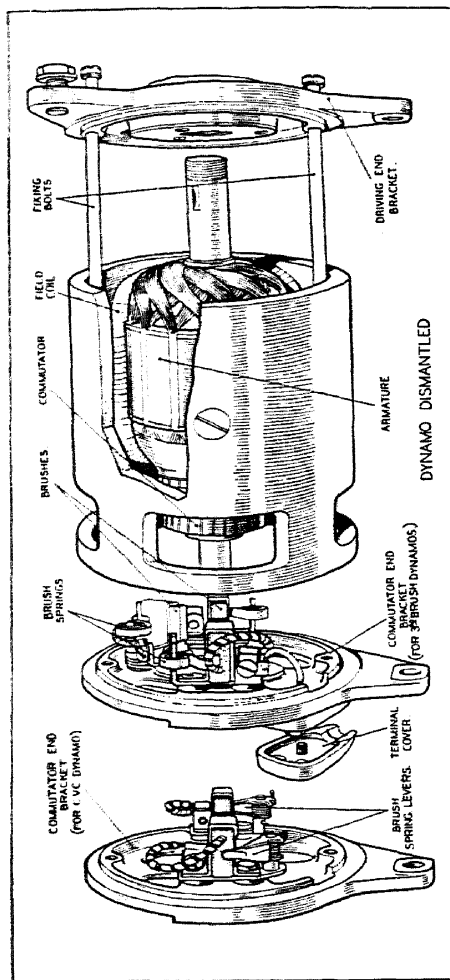DRIVING END BRACKET.

FIELD COIL

COMMUTATOR

ARMATURE

BRUSHES.

DYNAMO DISMANTLED

BRUSH SPRINGS

COMMUTATOR END BRACKET (FOR 3 BRUSH DYNAMOS.)

TERMINAL COVER

COMMUTATOR END BRACKET (FOR C.V.C. DYNAMO)

BRUSH SPRING LEVERS.

FIG. 62. LUCAS DYNAMO
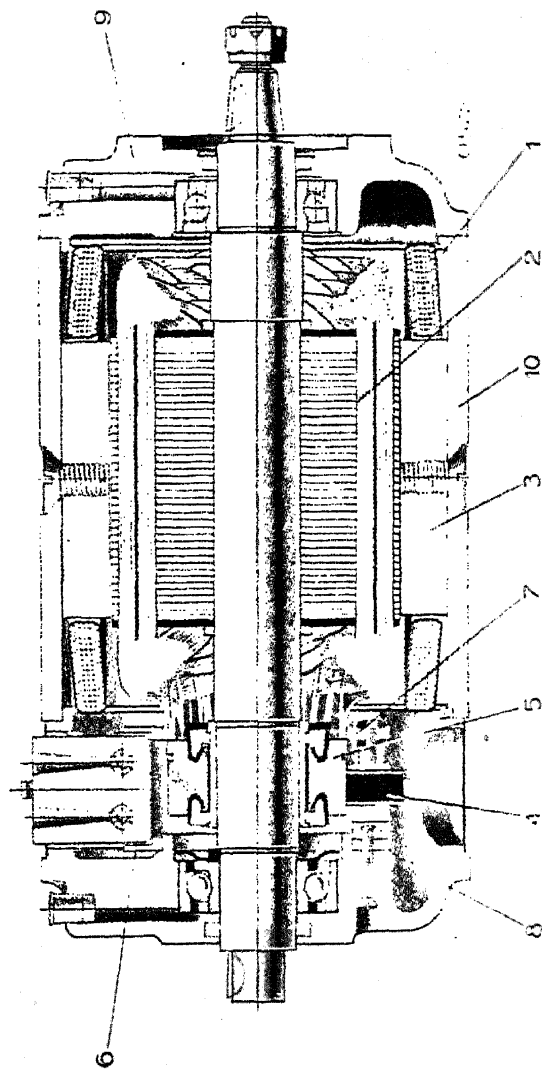
FIG. 63. SCINTILLA DYNAMO

1. Field winding.
2. Armature.
3. Pole shoes.
4. Carbon brush.
5. Commutator.

6. Porcelain terminal piece.
7. Carbon brush carrier.
8. Back end plate.
9. Front end plate.
10. Carcase.

4, slidable in carriers 7, are connected to leads brought in to the porcelain terminal piece 6, all these parts, together with one of the ball bearings, being supported in the back end plate 8. The other end of the spindle is supported by a ball bearing in the front end plate 9.

Dynamo Mounting and Speeds. A well-designed generator should run at least 20,000 miles without adjustment or replacing of the brushes being necessary. At the same time it should be mounted in a reasonably accessible position and such a position will generally also be favourable from the point of view of cooling. The output from a given size of generator is limited by its temperature, so that the question of cooling is of some importance quite apart from the question of damage to the insulation by an excessive temperature.

Dynamos are very frequently mounted somewhat high up in the engine and are often associated with a fan, both being driven by a V belt. In many dynamos, particularly large ones for use on buses, the dynamo is itself internally ventilated by the provision of a fan which draws or drives air lengthwise through the machine. A further advantage of the belt drive is the protection it gives against the ingress of oil since dynamos mounted on crankcases and driven by chains or gear wheels require special protection against the creeping of oil along the driving shaft.

Maximum speeds depend upon the size of the dynamo but it is not generally advisable to run at speeds in excess of 4,500 r.p.m. for any prolonged period. The maximum output of any dynamo is attained by speeds far below the maximum speed. At high speeds difficulties occur as regards commutation owing to the short time available in a weak field while brush jumping and vibration are also liable to affect performance. As an example, a commercial type of dynamo may be mentioned operating at 24 volts and delivering 145

watts. The cutting in speed is 360 r.p.m. but maximum output is attained at a speed of 500 r.p.m.. and the dynamo can be safely driven continually at a speed of 3,000 r.p.m. The weight of the dynamo is 32 lb.

Control Systems. The regulation of the output of a dynamo is complicated by the variety of conditions which have to be taken into account. The speed necessarily varies with variation of engine speed and the voltage and current output (which are interconnected but not proportional to one another) are thus continually varying within very wide limits. The cutout brings the dynamo into circuit at the lowest limit. which corresponds generally to a vehicle speed in top gear of the order of 15 m.p.h.. but considerable regulation is necessary beyond this. The demands for current by the starter. lights and accessories are very spasmodic and can only be dealt with by the battery for a limited period. The battery also requires consideration since any undue demands upon it must be made up and if it is of the lead acid type. it can only give good service and long life when maintained in a condition approaching full charge.

Various methods have been adopted to deal with these conditions, some being only semi-automatic, so that some regulation by the driver is necessary. while others are fully automatic and directed generally to varying the rate of charge so as to charge the battery fully; the charging rate being then reduced until there is a fresh demand. In all methods of output control the field is regulated in some way, either by some feature inherent in the construction of the dynamo or by some external means such as continuous or intermittent regulation of a resistance. Various methods of effecting control will be dealt with.

Electric Cut-out. When a dynamo is rotating at low speed, the voltage is not sufficient to overcome the

voltage of the accumulator, and it is necessary, therefore, to provide an automatic "cut-in" and "cut-out" which will only close the charging circuit when the voltage is high enough.

The cut-out is shown diagrammatically in Fig. 64. A soft iron core carries a coil of fine insulated wire A through which current from the dynamo D can always
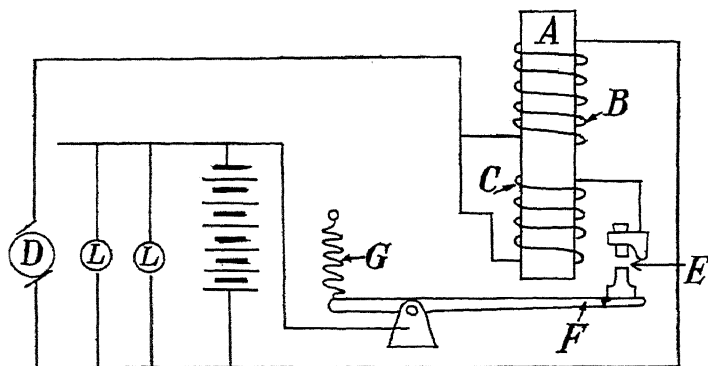

FIG. 64. DIAGRAM OF CUT-OUT

flow. A pivoted blade F is acted on by a spring G so as to tend to maintain the points E open in opposition to the magnetic force exerted by the core. When the speed of the dynamo is sufficient, the winding A magnetizes the core sufficiently to overcome the spring G and the points are closed, thereby enabling the dynamo D to charge the battery. This main charging circuit also includes a coil C around the core to maintain the points closed, since very little flows through the winding A when the parallel charging circuit is closed. A few turns of the heavy winding C have a magnetic effect on the core similar to the large number in the fine winding A. When the engine slows down sufficiently, the points open and the battery and dynamo are disconnected.

Various constructions of apparatus operating on this principle are used, and they are often associated with controllers for cutting down the dynamo output when the battery is fully charged.

Third Brush Control. In this well-known method for obtaining an approximation to constant current at all charging speeds, the voltage is controlled by the battery. Increasing distortion of the main field with increasing speed reduces the voltage applied to the field windings and thus limits the output. The system is shown in principle in Fig. 65. The field windings are of the shunt type, and the third brush is connected to the end of the shunt winding on the left side of the dynamo. The current collected by the third brush flows through the shunt field

FIG. 65. THIRD BRUSH CONTROL

windings to the main negative brush and then through the armature, which is of the series-parallel type described above. Half the current flows through the series of armature windings on the left of the figure, and half through the remaining armature windings on the right. The third brush, which collects positive current, is disposed ahead of the main positive brush, so that only part of the current flowing through the left side of the armature passes through the field windings, some of the armature windings being thus cut out of the shunt circuit.
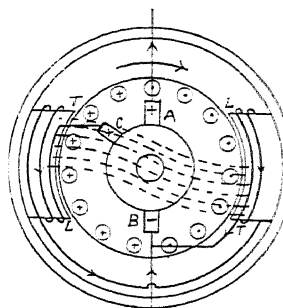
As the speed of the armature increases, the current produced passes from the main positive brush through the lighting system back to the negative main brush, and the current through the shunt windings is led

thereto from the third brush, and passes to the main negative brush. To follow the principle which renders third brush control effective it is necessary to consider the distortion of the field which takes place as the armature speed increases.

When the armature is rotating slowly, the lines of force run practically straight from pole to pole. The lines of force set up by armature reaction have a direction more or less circular. The resultant magnetic field formed by the combination of the lines of force produced by the field poles and armature reaction is shown in Fig. 65. The neutral line, which is always at right angles to the lines of force passing from pole to pole, is displaced from its vertical position, and assumes a more or less inclined position. The lines of force are more dense at the trailing tips T of the field pole, and are much weaker at the leading pole tips L.

Suppose the voltage from the main brush A to the main brush B to be $12\frac{1}{2}$ volts, then the voltage from brush A to the third brush C will be, say, 10 volts at a given speed, and this voltage will be applied to the shunt field windings, and will produce a flow of current of approximately $2\frac{1}{2}$ amperes.

As the speed of the armature increases, and increased armature reaction is set up, the lines of force become more dense at the trailing pole tips T, and correspondingly weaker at the leading pole tips L. The armature coils passing between the main brush A and the third brush C then cut a diminishing number of lines of force as the speed increases. The current picked up by the third brush C and passed through the shunt field windings is also weakened. On the other hand, owing to the higher speed of rotation, the number of wires cutting the lines of force per second is greater. These two influences balance each other so that

variations of the dynamo voltage and output are kept within workable limits.

To increase the charging rate or output the third brush C is moved farther away from the main brush A, and nearer the main brush B. In this way a larger number of armature windings between the brushes A and C is brought into use; the voltage applied to and the current passing through the field windings are therefore, increased. Conversely, the dynamo output is reduced when the third brush is moved nearer to the main brush A, thus reducing the voltage applied to the shunt field windings. Variations in output for a small adjustment of the third brush are considerable.

The simplicity of the third-brush machine is its greatest recommendation. Its chief defect is that it does not relate its output to the demand. The current supplied varies in the same direction as the voltage, so that a high voltage results in a high current before the regulating effect of armature reaction takes effect. The machine will therefore deliver a heavier current to a fully charged battery during a daylight run than it will to a discharged battery when the lights are switched on, for in the former case the effective voltage of the battery is high, while in the latter case it is low. The battery is thus overcharged and may be overheated on long day runs so that a larger battery is necessary and more frequent attention must be given to the topping up of the electrolyte.

Various methods have been suggested or used to remedy these deficiencies of the third-brush machine. One of the earliest consisted of a switch to cut off the charge at the discretion of the driver. In others, various types of indicators have been fitted on the dashboard to show the state of charge of the battery and act as a guide to the driver, but these were not fitted for more than a few seasons. The voltmeter type of

indicator can only indicate full charge or full discharge and gives insufficient guide to intermediate conditions.

In the U.S.A. a method which has been widely used includes a thermal switch incorporated in the dynamo so as to introduce resistance into the field circuit when the temperature rises. As the output depends upon increase of temperature, the method protects the machine and limits the output during a long daylight run. Further the output is higher on a cold winter day than a hot summer day, thus corresponding indirectly with the usual lighting requirements. The main defect of this method is its dependence upon the external cooling conditions of the dynamo which vary greatly according to its location relatively to the heated parts of the engine and the air currents produced by the fan.

A method which has been widely used in this country in connection with third-brush machines consists in the use of two charging rates in which a resistance is automatically inserted in the field by the lighting control switch when the lights are switched off, this resistance being short-circuited when the lights are switched on, so that the dynamo can then deliver its maximum output. A third charging rate is provided under the control of the driver who moves the switch to an extreme position to insert a further resistance in the field and reduce the charging rate to meet summer driving conditions. This system is shown in the diagram, Fig. 66. When the arm of the switch is in the summer or low charging position as shown, both resistances are in series with the field. Movement of the arm to the winter or high charge position short-circuits the lower resistance, while further movement to switch on the vehicle lamps short-circuits both resistances. This method while cheap and simple has limitations. It depends upon the judgment of the driver who may not be able to ascertain readily the

condition of the battery. While it may approximate to requirements for the normal running of private cars on fairly clear roads, it is likely to undercharge when the vehicle has little straight running but much
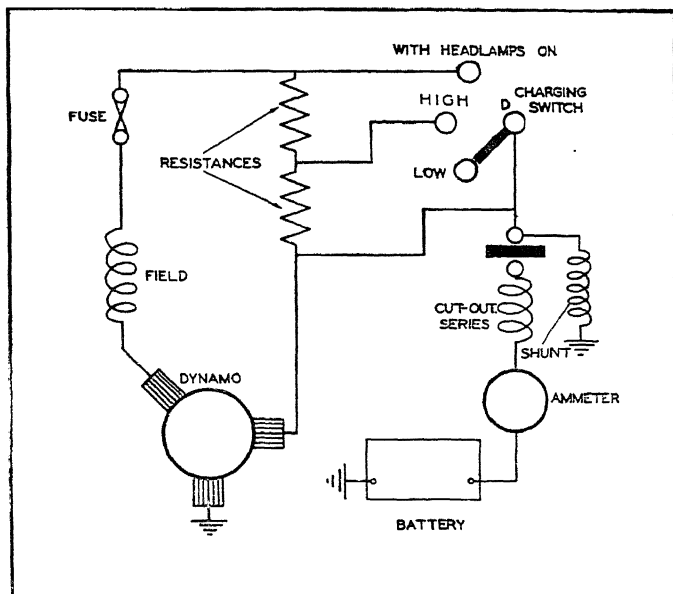

FIG. 66

starting and stopping. Characteristic curves associating speed and output in amperes of a dynamo under the three regulating conditions described above are shown in Fig. 67.

Constant Voltage Control Systems. The constant voltage or compensated voltage control systems also known as C.V.C. are entirely automatic and supply current of widely varying amount according to the state of charge of the battery, and the requirements

of the vehicle. The field of a shunt dynamo is controlled by a regulator of the vibrating armature type which very rapidly varies or cuts a resistance in and out of the field circuit in such a way that the average voltage remains substantially constant under all speed and power conditions. The momentary voltages are
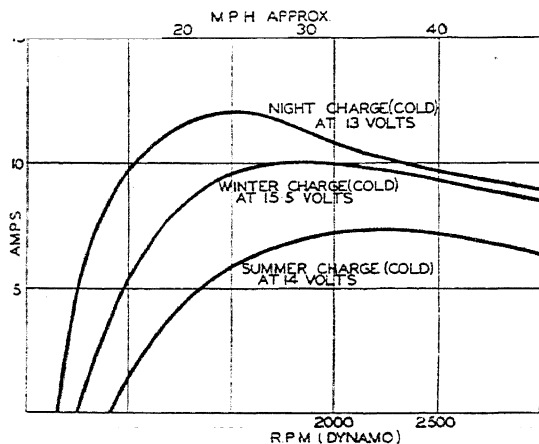

Fig. 67. Regulation Curves for 3-charge Rate Dynamo
(By courtesy of the Institution of Automobile Engineers.)

well above and below this average, but as the alternations are very rapid, being of the order of 50 per second, only the average value is perceptible or measurable by ordinary means. The apparatus in its various forms is completely automatic and possesses undoubted advantage over previous regulating systems.

Two main types are known, one utilizing a carbon pile variable resistance in series with the field, and the other, an ordinary resistance in the field circuit, controlled by vibrating contacts. The carbon pile is a well-known and effective method of regulation for electrical apparatus in general, and when applied to motor

control systems has given satisfaction in the past, but has finally given place to the vibrator type.

The carbon pile type shown diagrammatically in Fig. 68 utilizes that property of carbon discs 1 by which the resistance of the pile to the flow of current decreases as the pressure between the discs is increased. The pile 1 is pressed together by a spring, but the pressure of the spring is opposed to a varying degree by an electromagnet energized by the shunt coil or voltage winding 2 responding only to the voltage across the main + or – leads associating the dynamo 3, the bat-
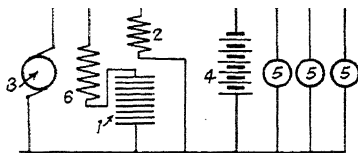

FIG. 68

tery 4, and the loads 5. The carbon pile is in series with the shunt field 6 and its resistance increases in response to a rise of voltage, since the increased force then exerted by the solenoid reduces the pressure exerted by the spring. The consequent increase of resistance decreases the current through the field winding and hence the strength of the field and the output voltage of the dynamo. The decrease of voltage will reduce the flow through the solenoid so that it exerts less force in opposition to the spring and the pressure on the carbon discs tends to increase, thereby reducing the resistance, so that the field current increases and the voltage rises and the cycle of control operations recommences. It is convenient to look upon the controlling operations as following a cycle of alternate increases and decreases of voltage which are rapidly corrected, but in practice such alternations cannot be detected by a sensitive meter and the action may be regarded as simply an immediate dead beat correcting effect following any change of voltage.

The carbon pile type of controller possesses several disadvantages. The resistance is permanently in series with the field winding so that a heavier current must be used to attain the necessary cutting-in voltage and speed. Rise of temperature while working varies the resistance after a time. Also the continual variation of pressure between the carbon discs tends to smooth the 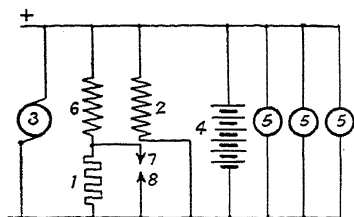surfaces thus changing the setting of the apparatus although this can be readily counteracted. The carbon type regulator can however carry a heavier current than the vibrator type.

FIG. 69

The circuit for the simplest form of vibrator type regulator is shown in Fig. 69. It has one set of regulator contacts which intermittently insert a resistance 1 in the field circuit. These contacts consist of a movable element 7 and a fixed part 8. Contact 7 is closed on to contact 8 by a spring when the dynamo 3 is at rest and the field circuit is then from the brush + through the field winding 6 and the contacts 7, 8 to the – brush. The field resistance 1 is connected across the contact points and is in series with the field winding 6 when the points 7, 8 are opened by the shunt coil 2 which acts in opposition to the closing spring for the contacts.

As the dynamo speeds up and the voltage attains a pre-determined value, the shunt coil 2 overcomes the closing spring of the contacts 7 and opens them, thus inserting the resistance 1 in series with the field winding 6. The voltage then drops so that the contacts close and the resistance 1 is short-circuited. This cycle of operations continues at high speed as long as the engine is running. The higher the speed of the engine, the

greater is the amplitude of the vibrations of the movable contact and the longer the open intervals in relation to the closed intervals, so that though the dynamo voltage tends to increase with speed, the average resultant voltage acting on the battery is kept substantially constant. This action takes place in a satisfactory manner up to certain speeds. At higher speeds, for example, speeds above 3,000 r.p.m., the voltage tends to increase and further control may be necessary.

Such further control is obtained by cutting out the field winding entirely when the amplitude of the vibrations increases sufficiently. The method is shown
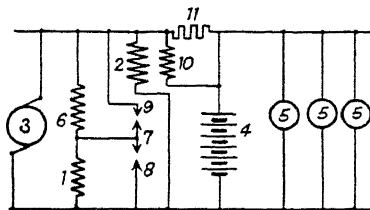

Fig. 70

diagrammatically in Fig. 70. The system is similar to that shown in Fig. 69, but the movable contact 7 when sufficiently attracted engages an additional fixed contact 9 and short circuits the field winding 6 entirely. The resistance contacts 7, 8 then remain open and the shorting contacts 7, 9 open and close intermittently. When the shorting contacts are open, the field resistance 1 remains in series with the field 6 until the speed drops sufficiently for contacts 7, 8 again to close intermittently. Only the theory of operation has been described above. In practice, however, a series or current winding 10 is necessary to assist the voltage winding 2. This winding could be arranged to carry the whole load, or as shown a shunt 11 may be provided so that the winding 10 only carries part of the load. Alternatively, the current winding 10 may be arranged to carry the whole of the battery current or only a part.

This current winding is provided to prevent

overloading of the dynamo when the battery is in a low state of charge. The starter battery must have a low internal resistance to deal with the heavy starting currents, and, when discharged, its voltage is low so that the voltage winding of the regulator does not respond and the dynamo output would become excessive while endeavouring to bring the voltage up to the normal operating voltage of the system. If the lamps are also switched on, the dynamo is even more heavily overloaded. The current winding avoids this difficulty by holding the resistance contacts open longer, or the shorting contacts closed longer, according to the speed of the dynamo ; the reduction of voltage limits the output of the dynamo.

The double-contact regulator is able to deal with larger currents than the single contact type since the work is shared between two pairs of contacts, while a smaller resistance in series with the field can be employed ; but it is more complicated and expensive and requires more careful manufacture and adjustment. Its employment for the heavy loads and exacting requirements of heavy commercial vehicles would appear, however, to be fully justified while the single contact type may be adequate for the smaller power units of private cars.

Several practical embodiments of the principles described above will now be described in detail.

Lucas Compensated Voltage Control. This widely used method of control is of the single contact type and responsive in the usual way to battery voltage, but having in addition superimposed thermostatic control responsive to general temperature, and giving a slightly higher rate of charge for a short time after the engine has started. The wiring diagram for the system is shown in Fig. 71, and the arrangement of the regulator unit in Fig. 72.

The regulator and cut-out are arranged on the same

base which also includes a number of terminals for the various auxiliaries. The two are, however, electrically independent with an entirely separate arma-
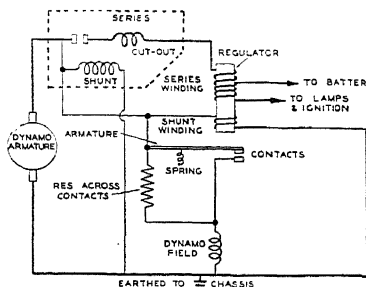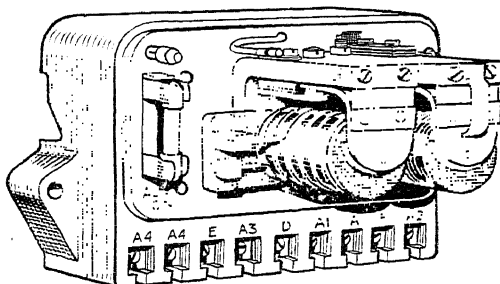

FIG. 71. LUCAS CV CONTROL

FIG. 72. LUCAS CVC REGULATOR UNIT

ture, although field systems are common over a portion of the magnetic path.

The cut-out has the usual shunt winding and the series winding through which the whole current passes. The regulator windings include a shunt voltage winding connected directly across the dynamo and two series or current windings, one of which carries the full current to the battery, lamps, ignition and accessories, while the other carries the current only of the lamps, ignition and the accessory loads. These two coils are

in series and assist each other in energizing the magnet and operating the armature.

As the dynamo speeds up, the cut-out is first operated, so that current is then supplied to the regulator. When the dynamo voltage reaches a predetermined value, the magnetic field winding due to the voltage or shunt winding becomes sufficiently strong to attract the armature, thereby opening the contacts and inserting the resistance in series with the dynamo field. The dynamo voltage is thus reduced, the magnetic field weakens, the armature is returned by its spring, and the contacts close so that the voltage rises. This cycle is repeated and the armature set into vibration at a frequency of the order of 50 per second.

The series windings provide a compensation for this method of control to prevent overloading of the dynamo when the battery is in a low state of charge. The separate series winding to the lamps and the ignition exerts a further compensating effect to prevent overloading of the dynamo when the accessories are switched in.

The cut-out and the regulator are mounted on the same base as shown in Fig. 72, the cut-out being shown on the right hand and the regulator on the left. The regulator includes a right-angled member mounted pivotally on the supporting plate by a thin flexible steel spring, one arm of the angle plate being attracted by the armature and the other carrying a contact which co-operates with a fixed contact to make and break the short circuit for the dynamo field resistance.

Additional compensation is provided for variations of temperature with the object of modifying the charging rate to suit the requirements of the battery under all climatic conditions, since in cold weather the voltage required to charge the battery is higher than it is in warm weather. Also, normally the voltage

setting of the regulator is higher when warm than when it is cold.

The effects of temperature variation are reduced to a minimum by a thermostatic strip incorporated in conjunction with the regulator adjustment spring and arranged to alter the voltage setting. This strip consists of two metal strips, having different coefficients of expansion with heat, bonded together throughout
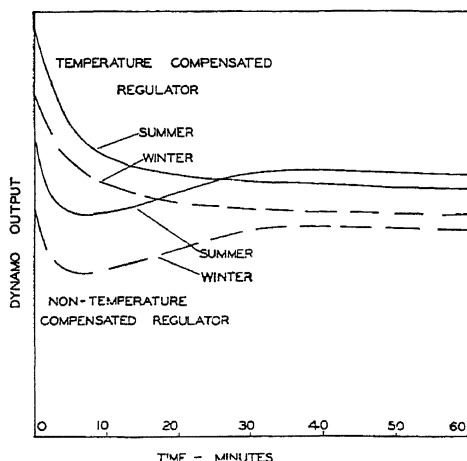

FIG. 73. LUCAS DYNAMO CONTROL

their length so that the strip bends as the temperature varies. This bending causes the spring pressure applied to the regulator armature to alter with changes in temperature, and consequently the setting of the regulator alters accordingly. In cold conditions, the voltage setting is raised, while under warmer conditions it is lowered.

This enables a higher average setting to be obtained during the winter months, so compensating for the increased battery charging voltage during cold weather.

In addition, a higher initial setting is given at the beginning of a run which enables the dynamo to give an increased charge during approximately the first half hour. This quickly restores to the battery the energy used up in starting.

The comparative outputs of temperature compensated and non-temperature compensated equipments under winter and summer conditions are shown in Fig. 73.
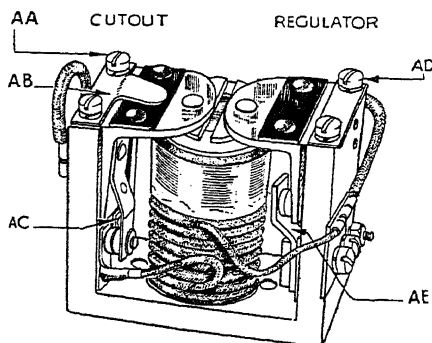

FIG. 74. C.A.V. BOSCH COMBINED CUT-OUT AND REGULATOR

C.A.V.-Bosch Combined Cut-out and Regulator. A simple compact form of control element can be obtained by the use of a single coil in conjunction with two operating members. A unit of this type made by C.A.V. Bosch, Ltd., is shown in Fig. 74. The core carries both shunt and series windings for the cut-out and regulator. The movable part of the cut-out element shown on the left includes an armature of angle shape pivoted by a spring to the top of the U-shaped bracket, the movable contact being carried by an arm AC secured to the armature which is positioned by slacking off the holding screws AA, adjusting the armature and re-tightening the screws. The holes through which the screws pass are enlarged to allow

this adjustment. Further adjustments can be made by bending the strips AB, AC. The regulator on the right-hand side is of similar construction and its spring pivot is similarly adjusted by screws AD. When the contacts are closed, the air gap between the armature tip and the core can be adjusted by bending the fixed contact bracket AE.
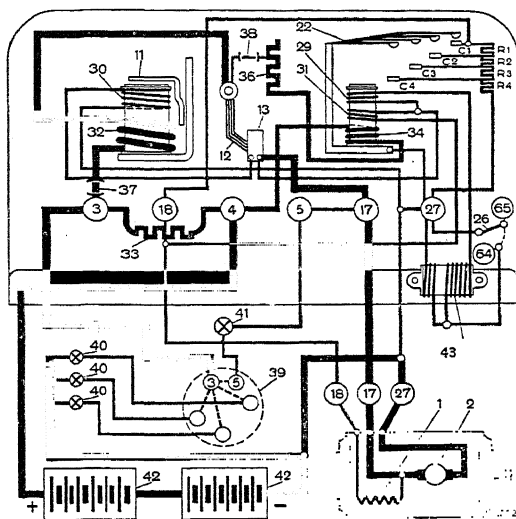

Fig. 75. Scintilla C.V.C. System

Scintilla Automatic Control System. The main characteristic of this system is the provision of a number of resistances which are inserted in series with the field winding as dynamo speed increases. Fig. 75 shows the wiring diagrams associating the dynamo, battery, cut-out, voltage-controller, and load. Fig. 76 shows the cut-out and voltage-controller assembly, while Fig. 77 shows a similar view with the electromagnets in section. The whole system operates on

24 volts. When the armature rotates, current induced in the armature windings passes from the positive pole through the field 1, the circuit to the negative pole of the dynamo being completed through contact 18, regulator armature 22, and contact 27, armature 22 then engaging all the contacts $C1$, $C2$, $C3$, $C4$, so that all the resistances $R1$, $R2$, $R3$, $R4$, are short-circuited. The dynamo is thus excited and the voltage rises as the speed increases. The voltage coil 30 in the cut-out is connected across the $+$ and $-$ terminals of the dynamo through the contacts 17 and 27, and the contact bar 13. As soon as the voltage attains a value
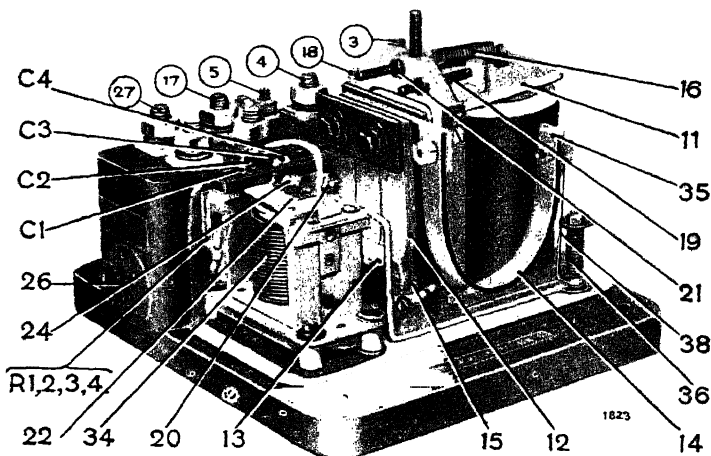

FIG. 76. SCINTILLA C.V.C. REGULATOR AND CUT-OUT

(*Description of Parts i*)

11 Cut-out armature
12 Cut-out main brush
13 Contact bar
14 Connecting band
15 Cut-out trailing brush
16 Spring for cut-out armature
19 Adjusting screw for cut-out armature

20 Adjusting screw for regulator tension spring
21 Adjusting screw for cut-out armature tension spring
22 Regulator armature with contacts
24 Tension spring for regulator armature
26 Connecting link for summer winter adjustment

sufficiently in excess of the working voltage, the armature 11 is attracted against the pull of its spring 16 and the cut-out main brush 12 makes contact with the contact bar 13, thereby completing the main circuit from the positive to the negative pole of the dynamo through the contact 17, contact bar 13, main brush 12, cut out current coil 32, connecting band 14, fuse 37, terminal 3, and then through either of two parallel circuits: (a) the battery circuit through shunt 33, terminal 4, batteries 42, and terminal 27; (b) load circuit through switch 39, loads 40, and terminal 27.

The regulator armature 22 is attracted against the pull of its spring 24 by magnetic forces due to voltage winding 29, demagnetizing winding 31 and current
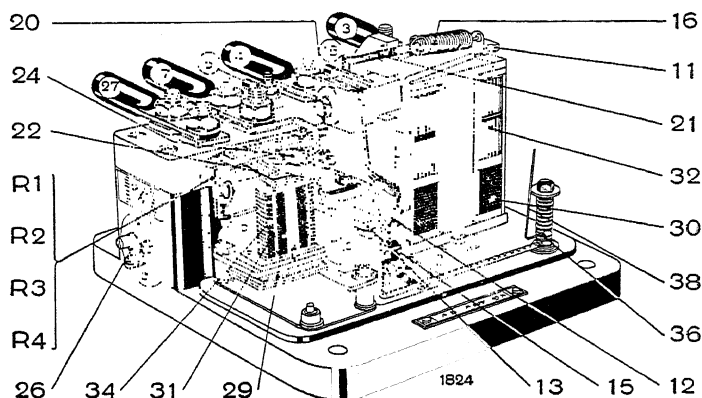

FIG. 77. SCINTILLA C.V.C. REGULATOR AND CUT-OUT

Figs. 75, 76, *and* 77)

29 Regulator voltage coil
30 Cut-out voltage coil
31 Regulator demagnetizing coil
32 Cut-out current coil
33 Shunt
34 Regulator current coil
35 Cut-out current coil terminal
36 Series resistance for regulator current coil

37 Fuse
38 Fuse in regulator current coil circuit
39 Switchboard
40 Consumers
41 Control lamp
42 Two 12-volt batteries in series
43 Resistance for summer and winter charge

winding 34. The voltage winding 29 is always connected directly across the + and − terminals 17, 27 of the dynamo through contact bar 13 and resistances 43 for summer and winter charging rates. The demagnetizing winding 31 is similarly connected to contact bar 13, but returns through contact 18 and regulator armature 22 to terminal 27. The closing of the cut-out main brush 12 also completes a circuit from brush 12, fuse 38, and resistance 36 through the regulator current coil 34 to terminal 4; that is to say, current coil 34 is in parallel with shunt 33, so that it carries a current proportional to the dynamo current output. Part of the main current to the battery then assists the voltage coil 29, and less voltage is necessary at the dynamo terminals to attract the armature 22. The current coil 34 thus adds to the controlling effect of the voltage coil 29, a controlling effect depending upon: (a) the current to the battery, and (b) the current consumed by the load. Excessive demand upon the dynamo for current is thus prevented when the battery is badly discharged. The current coil 34 is adjusted by means of resistance 36; maximum dynamo output results when all the resistance is in circuit, while short circuiting the resistance gives minimum output. The adjustable contact is soldered permanently in position to adapt the output control generally to the size of dynamo with which the control unit is associated and the requirements of the vehicle (headlamps, interior lights, ignition, starting, etc.). Any size of control unit is thus adaptable for use in systems of widely differing output.

As the armature 22 is attracted more strongly under the combined effect of increasing voltage and current, contact $C1$ is first opened, thereby inserting resistance $R1$ in series with the field 1 resulting in a decrease of voltage at the dynamo terminals. Immediately

resistance $R1$ is thus connected in series with the field, the voltage across the demagnetizing coil 31 decreases and a self-induced current is set up in the coil in the opposite direction, thus weakening the magnetic attraction of the voltage coil 29. The contact $C1$ then closes under the influence of the spring 24, short-circuiting resistance $R1$. The voltage increases and a self-induced current again flows through the de-magnetizing coil 31; but this time it assists voltage coil 29. Contact $C1$ then opens, thus recommencing the cycle, which is repeated at the rate of about 50 per second so that no variation in the light beam can be observed. As the speed of the dynamo increases, the resistance $R1$ exerts insufficient control of the rising voltage and contacts $C2$, $C3$, $C4$ are cut out in succession, thus inserting resistances $R2$, $R3$, $R4$ in the field. This regulation of the field current is shared among four pairs of vibrating contacts so that the load on individual contacts is reduced to a minimum and the life of the regulator is prolonged.

Sticking of the contacts 12 on contact bar 13 due to burning of the contact is very unlikely as arcing at this point has been practically eliminated by the provision of the cut-out trailing brush 15. Should this take place, however, when the dynamo is stationary, fuse 37 protects the dynamo and regulator from damage by battery discharge. Should fuse 37 blow, fuse 38 will also blow, thus isolating the regulator current coil 34.

When the dynamo voltage drops below that of the battery, a reverse current from the battery through the current coil 32 to the dynamo opposes the magnetizing effect of the voltage coil 30, so assisting the return of the cut-out armature 11 by means of the tension spring 16 whereby the main current connection between the brush 12 and contact bar 13 is interrupted. After

the main connection is broken, the trailing brush 15 interrupts the reverse current so that arcing of the main brush does not take place.

By means of the switch 26, the regulator may be adjusted for summer and winter charging rates. For the winter rate the connection between the voltage coil 29 and battery terminal 27 is made through both resistances 43 but for the summer charging rate one of the resistance coils is short-circuited.

The ammeter indications with constant-voltage control systems are very different from those with systems using third brush dynamos. In the latter the ammeter shows a practically constant charge rate over the whole range of speed whatever the condition of the battery; while in the former great fluctuations take place, the charging rate being very low once the battery is fully charged, but increasing as soon as the lights or other components make a noticeable demand for current. The immediate result of switching on lamps with a fully charged battery may be a discharge reading on the ammeter but the high voltage of the battery soon falls and the regulator responds until the dynamo output balances the load.

STARTING

Engine Requirements. The selection of a suitable starting motor depends essentially upon the characteristics of the engine. A large number of independent factors determine the final requirements, the following being the most important—

(1) Temperature of engine or cooling water.

(2) Viscosity of lubricating oil.

(3) Area of working surfaces in contact with an oil film including—

Pistons, their number, diameter, and length of bearing area.

Bearings, crankshaft and big end.

(4) Speed of rubbing of working surfaces depending upon piston stroke, diameters of bearings.

(5) Clearance of working surfaces, particularly bearing clearances.

(6) Speed and compression ratio, neither of these by itself having much effect.

It will be clear from these considerations that the starting torque necessary can only in practice be determined by measurement of the completed engine and can only be estimated in advance by analogy with a very similar engine whose characteristics are known.

Table I gives some particulars of typical English engines. In each case the temperature was about − 5° C., a somewhat severe condition, while the speed was about 50 r.p.m.

TABLE I

	n Number of Cylinders	d Diameter mm.	s Stroke mm.	T Torque lb. ft.	V Volume c.c.	V/T
(1)	4	63	95	30	1190	40
(2)	6	57	83	32	1270	40
(3)	6	63	102	88	2000	23
(4)	6	75	106	126	2780	22

The fifth column gives the approximate engine capacity V in cubic centimetres. The sixth column gives the ratio of engine capacity to torque. The torque resistance of the two larger engines is much greater at this low temperature than that of the smaller engines after full allowance is made for their greater capacity. Under actual running conditions with the engines hot, the figures in the last column would be much larger and more equal to one another, and the starter would then have a large power surplus, but it has to be made

large enough to deal with the conditions of extreme cold.

The starting torque under similar conditions for many American engines of comparable size is less.
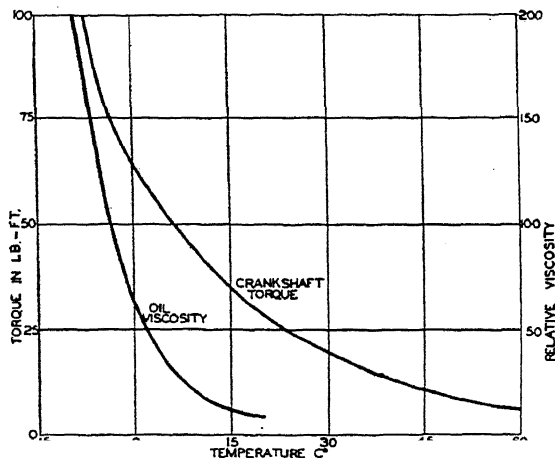

FIG. 78. EFFECT OF TEMPERATURE ON CRANKING TORQUE AND OIL VISCOSITY

(*By courtesy of the Institution of Automobile Engineers.*)

The great variation in torque with temperature is shown graphically in Fig. 78, and indicates clearly the seriousness of the starting problem at low temperatures, and the necessity of providing a starter capable of developing a torque far in excess of that required under ordinary running conditions. The viscosity of engine oil is also very much greater at low temperatures.

The starter must also be powerful enough to turn the engine at a speed such that the carburettor will furnish a proper mixture. Some carburettors and induction systems require a speed of 70 r.p.m. while others,

particularly the so-called self-starting carburettors can function at lower speeds.

It is customary to start the engine with the clutch engaged so that the resistance of the heavy gear oil in the gearbox is added to that of the engine. This is a serious addition and tests at freezing temperatures have shown that the starting speed can be raised by a figure of the order of 15 per cent by disengaging the clutch.

The reduction of torque and current consumption as the motor speeds up is due to the generation of a counter electromotive force in the armature, due to the movement of its windings across the magnetic lines of force spreading inwards from the field poles. In this way it behaves as if it were a generator and as this counter E.M.F. opposes the battery E.M.F., the consumption of current falls off and the battery is relieved as the speed increases. But the current even then is so heavy that the starter should not be used more often than is necessary and only for the shortest interval necessary to start the engine. Misuse of the starter results in overheating, damage to the plates, and excessive discharging of the battery. If the starter is only used for an interval of the order of a second, the battery regains its normal voltage very quickly. A given total discharge time expended in a large number of short discharges exhausts the battery less than the same time expended in a small number of longer discharges.

The primary requirement of all starter motors is the capacity to exert a very heavy torque when starting and at low speeds so as to accelerate the engine rapidly to a suitable starting speed. As the speeds rise the torque decreases, the rate of consumption of current is reduced, and the voltage rises. If, however, the torque is insufficient, the starter will be

working under the worst conditions for a longer period and the demand upon the accumulator will be severe.

To meet these requirements starter motors are series wound, the whole of the current through the armature also passing through a comparatively few turns of heavy winding on the field poles. The energy required to produce a powerful magnetic field between the poles
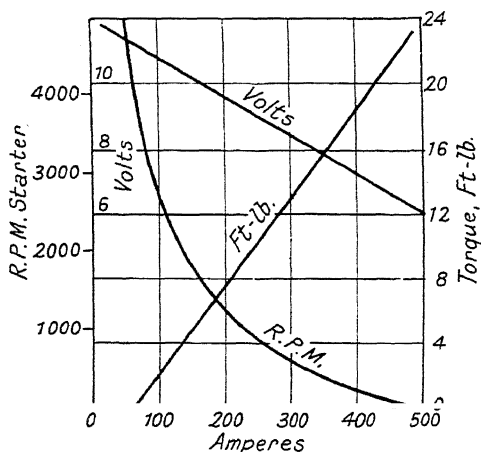

FIG. 79. SCINTILLA STARTER MOTOR

is much less than that required by the armature. The resistance of field windings is low and the drop of E.M.F. in the field circuit is therefore less than in the armature.

Various figures relating to the performance of a 2 h.p. 12 volt Scintilla starter motor are included in the diagram, Fig. 79, and illustrate the behaviour in general of series wound motors. For every value of the current consumption from 0 to 500 amps. the diagram gives corresponding values for voltage, speed, and torque exerted by the starter. The locked torque value of 22 ft.-lb., that is with the starter stalled, is

attained with a current of 470 amp. and a voltage just over 6. This high value gives rapid acceleration, so that the total energy supplied by the battery is not excessive. The speed and torque vary in a more or less inverse manner. The maximum efficiency is attained at a speed of about 1100 r.p.m., and a current consumption of approximately 220 amps.

The Starter Motor. An electric motor may be regarded as a reversed dynamo and vice versa. In one case mechanical energy is converted into electrical energy while in the other case the conversion is in the reverse direction. The two have the same essential parts, that is, the field magnets, armature, commutator, and brushes, but both have in addition certain specialized parts. The dynamo has means for controlling output while the starter motor has special driving mechanism. The starting and generating requirements on motor vehicles are, however, so different that the two machines, though externally similar, must have very different electrical characteristics, although the principles of generation and commutation dealt with in the dynamo section are common to both. Several examples of starter motors will be described in detail later in connection with the different systems, but the main features peculiar to starter motors will be dealt with now.

On the interior of a cylindrical steel body are secured the laminated poles, two, four, or six being provided according to size. Countersunk screws hold the pole pieces in position. The armature is made up of a number of thin soft iron plates clamped together and keyed to the spindle, the construction being the same as that of the dynamo described earlier. Longitudinal slots in the peripheries of the plates receive the windings, the slots being undercut and the windings held in by wedges or filling pieces to resist centrifugal force.

Copper bars of relatively large rectangular section constitute the field pole windings, these contrasting greatly with the finer wire windings of the shunt field poles of the dynamo.

At the back end of the casing, openings are provided to give access to the brushes which very occasionally require cleaning to ensure that they move freely in their holders. The openings are covered by a light metal band readily removable. The brushes are carried by the end cover plate which also carries the end bearing. Plain bearings are always used on starters since their total running time is small and bearing wear and frictional resistance hardly need consideration. This is in contrast to dynamos, in which ball bearings are commonly used since they have to run continuously at high speeds with little friction.

The poles are so wound that they are alternately N and S, the magnetic circuit being completed through the casing. The direction of the magnetic flux is indicated approximately for a four-pole machine in Fig. 80. The path through the air in the interior will of course be modified from that shown by the presence of the iron of the commutator and during rotation will be unsymmetrical. In this way there are produced several strong magnetic axes arranged diametrically, one for each pair of opposite N and S poles. In a simple two-pole machine as shown diagrammatically in Fig. 81, the axis $X - X$ passes through the two poles. The current is led through the brushes, the commutator and the armature windings in such a way that the part of the armature momentarily on the axis Y - Y becomes in effect another powerful electro-magnet of the polarity indicated. Although the armature rotates, the position of its magnetic poles does not change. As the commutator sector connected to one armature winding leaves the brush, another takes its place so

that the point at which the current enters the armature does not move and the polarity of the armature is unaltered. Four- and six-pole machines have respectively two and three magnetic axes due to the field magnets alternating with the commutator magnetic axes.

The motor thus derives its torque from the magnetic attractions between opposite poles and the magnetic
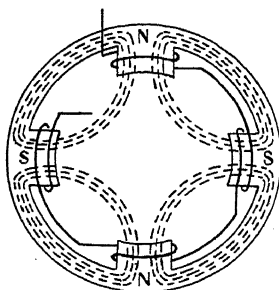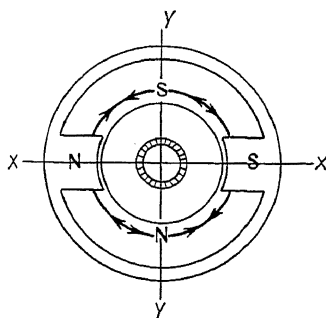

FIG. 80   FIG. 81

repulsion between like poles. This is indicated by the arrows so that the armature will rotate in an anti-clockwise direction.

The above explanation is of a somewhat popular character. It is more correct to say that the conductors in the armature when carrying the current pass through and interact with the magnetic flux in the field due to the pole windings in such a way that the two exert a definite mutual reaction whereby they tend to move relatively to one another. As the magnetic field is fixed, and only the conductors are free to move, the armature rotates. All the windings are arranged so that these many interactions between the field flux and the armature conductors are cumulative, with the

result that the armature is capable of exerting a very powerful turning moment or torque.

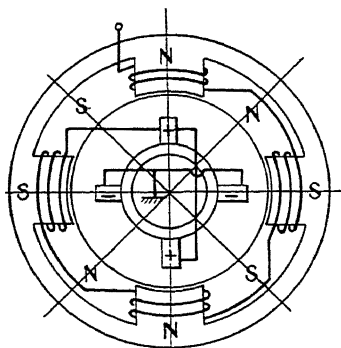A four-pole, four-brush machine is shown diagrammatically in Fig. 82. The main supply lead carries current to the four-pole windings in succession, the direction of the winding on each pole being such that the polarities are as indicated. There are thus two main axes through the field poles at right angles to one another. From the pole windings current passes to the two − brushes, from each of which it passes through two paths in the armature windings to the + brushes, and thence to earth. The interaction between the armature windings and the field flux may be regarded as forming two magnetic axes which bisect the angles between the two magnetic axes due to the fixed poles. If the directions of the windings are such that the two sets of axes have polarity as indicated, the armature will rotate in a clockwise direction. This is a series machine, all four field windings being in series with one another, and with the armature as a whole, although the internal circuits in the armature are in parallel.

Fig. 82

Another design of four-pole, four-brush machine is shown in Fig. 83, but in this case only two of the four poles are wound, their windings being in series with one another and with the armature. The other two poles are unwound or consequent poles, their polarity being of opposite kind to that of the wound poles.

The winding of the poles is often a series parallel arrangement as shown in Fig. 84. In this case the incoming lead divides and each part is led to two poles, one S and one N, in series with one another, the two circuits then leading to the two − brushes. The two circuits are not led to the two + brushes inde-
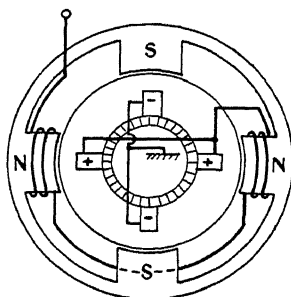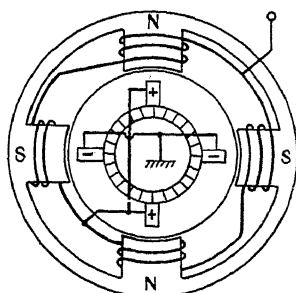

Fig. 83

Fig. 84

pendently but have a common connection thereto, thus equalizing the pairs of fields and ensuring equal potentials at the brushes.

Starter Drives. With few exceptions the starter motor is a high-speed machine having a toothed pinion which engages a ring of teeth cut in the rim of the flywheel or in a ring which is bolted to the flywheel. The exceptions consist of the dynamotor, a special machine which at low speeds starts the motor and at higher speeds generates current. Dynamotors were at one time widely used and proved entirely satisfactory and reliable. They were usually connected by a silent chain to the crankshaft or to the clutchshaft so as to run at a higher speed, and were definitely superior to the usual toothed drive in giving quieter starting. Their speed was between two and three times that of

the engine. In view of their dual functions, they were substantially larger and heavier than either the dynamo or the motor which they replaced. This characteristic, coupled with the great increase in speed of modern engines, has led to their elimination in favour of the two-unit system. In some cases the dynamo was bolted directly, or connected by a spring coupling, to the end of the crankshaft, but this arrangement, though simple, reliable and attractive in many ways, called for a specially heavy machine to produce the necessary starting torque.

Frequent engagement of toothed gear wheels is not mechanically desirable. Silent running of starter gearing when engagement has taken place is practically impossible to maintain over a long period, while damage to the teeth during engagement is likely ultimately to result in jamming of the starter pinion in the flywheel teeth. The teeth on one or both of the gears are chamfered on the non-working faces firstly, to reduce the probability of the teeth engaging end to end when the pinion is moved axially, and, secondly, to increase the chances of their slipping easily between one another. But this does not wholly eliminate wear which occurs mostly on the flywheel ring, particularly when the teeth are cut in cast iron. Due to the compression, engines always stop in one of two or three positions, so that starting wear is limited to the half-dozen or so teeth in each position of the flywheel. There are two such positions for a four-cylinder and three for a six-cylinder engine.

In one of the oldest and most widely used classes of starter, the starter switch supplies the full starting current at once to rotate the armature. The pinion is so mounted by a screw thread on the armature spindle that, due to its inertia, it lags behind and also moves axially into engagement with the flywheel teeth. When

it reaches the limit of its axial movement it is fully engaged and transmits the drive. The pinion is screwed out of engagement when the engine fires. Should the engine back-fire, very heavy stresses are imposed on the teeth and the starter rotor, while re-operation of the starter switch before reverse rotation has ceased, creates additional stresses. The pinion has been associated with a strong helical spring but this gives only a limited cushioning effect and spring breakages are not unknown.

This type of starter drive is properly described as an inertia type, since energy stored up by the armature during the pinion engaging period is used in conjunction with a cushioning spring, to start rotation of the engine. It has been generally known for many years as the Bendix drive, after its inventor.

Modern designs are directed towards the avoidance of clashing of the teeth and of severe starting stresses. This is particularly important in large commercial vehicle engines of the compression-ignition type with their high compression ratios. Where the full current is applied at once to rotate the armature, special cushioning and clutch slipping devices are employed. These are largely used on private cars and commercial vehicles of similar power, but for the heavy commercial engines, the pinion is first moved into engagement by relatively small forces and only then is the full current supplied to the armature.

Bendix Starter Pinion. This method of engaging the starter pinion with the ring of teeth on the flywheel has been very widely used both in this country and in America. Fig. 85 shows an overhung pinion as used on an M.C.L. starter motor of 5 in. diameter. The toothed pinion A is provided with a counterweight B so that it is always out of balance, and it is mounted by a screw thread on the outside of a sleeve

carried by the armature shaft. The sleeve is con-
nected to the armature shaft by means of a spring C
forming an elastic drive, the ends of the spring being
secured to collars D E bolted respectively to one end
of the sleeve and to the outer end of the shaft. When
the starter commences to turn, the pinion A screws
along the sleeve into engagement with the flywheel
teeth until it abuts against the collar F on the inner
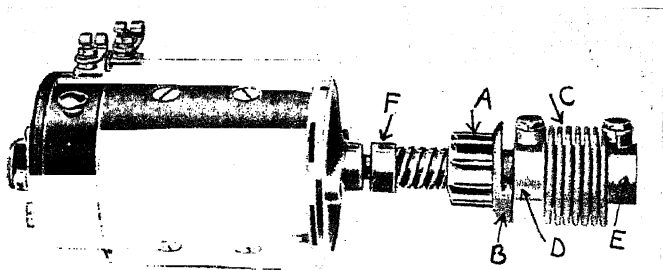end of the sleeve. The drive is then transmitted from

Fig. 85. M.C.L. Starter with Bendix Drive

the starter shaft through the spring C, the screwed
sleeve, and the pinion A to the flywheel. When the
engine fires the pinion is rotated faster than the sleeve
and is thus screwed outwards clear of the flywheel.

Various modifications in detail have been used. In
some cases the pinion moves away from the body of
the starter, the spring being located between them.
An end bearing is often provided, thus giving much
better support for the pinion.

A starter motor with inertia type drive made by
Joseph Lucas, Ltd., is shown partly dismantled in Fig.
86, the torque effect being cushioned by the main
compression spring. On the splined end of the armature
shaft is mounted the externally screwed sleeve carrying

MAIN SPRING

SCREWED SLEEVE

PINION

RESTRAINING SPRING

PLAIN SLEEVE

DRIVING END BRACKET

ARMATURE

STARTER SWITCH

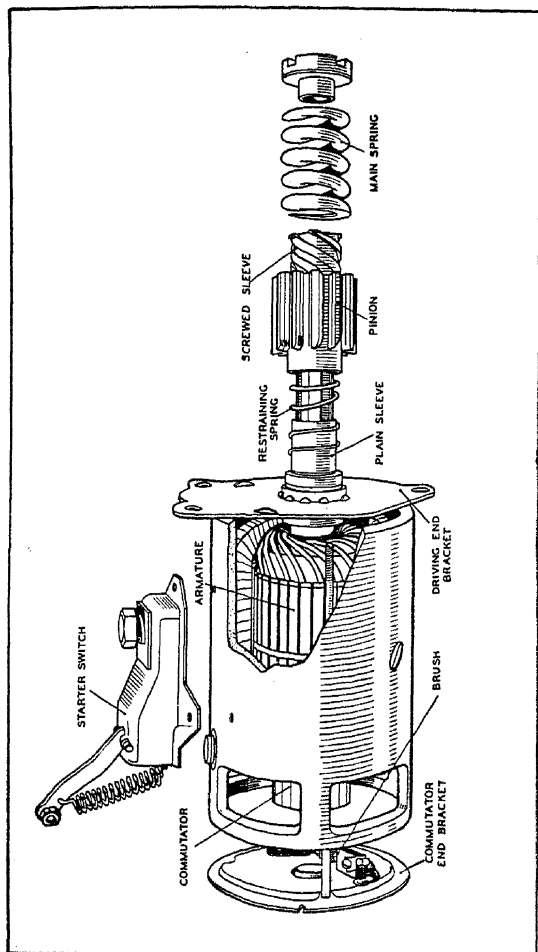BRUSH

COMMUTATOR

COMMUTATOR END BRACKET

FIG. 86. LUCAS STARTER WITH BENDIX DRIVE

the pinion. When the parts are assembled, they are secured in position by the end shaft nut which is screwed on to the reduced end of the shaft and is then held against rotation by a cotter pin.

When starting, the pinion, due to its inertia, lags behind and screws along the sleeve until it is in full engagement with the teeth on the flywheel and abuts against the flange on the plain sleeve. The resistance to its rotation as it takes up the drive causes it to rotate slightly backwards relatively to the shaft, thereby forcing the screwed sleeve outwards against the resistance exerted by the main spring.

In both types of inertia starter drive, the pinion and armature at first accelerate very rapidly, a speed in the neighbourhood of 1500 r.p.m. being attained in less than a second before the pinion begins to take up the drive. The kinetic energy is partly absorbed by the torsion or compensation spring according to the design of drive and finally most of it is expended in rotating the engine. In spite of the cushioning effect of the springs, the armature in effect gives a violent blow to the flywheel rim and the stresses in the armature shaft and other parts are very severe. To summarize, during the first stage the armature accelerates while the pinion slides into mesh. During the next stage, the armature continues to accelerate and compresses the spring until the torque which the starter is capable of exerting equals the resisting torque of the engine. The armature then slows down and stops when the stress in the spring has increased to its maximum value. During this stage some energy is expended by the starter motor itself on the spring. This stage may be followed by a recoil of the armature and a number of oscillations may occur, but this depends upon how easily the engine starts. These steps are shown in Fig. 87.

The current taken by the starter also varies during the whole period in dependence upon the variations in speed and torque. Although the torque or compression spring to some extent tempers the blow when
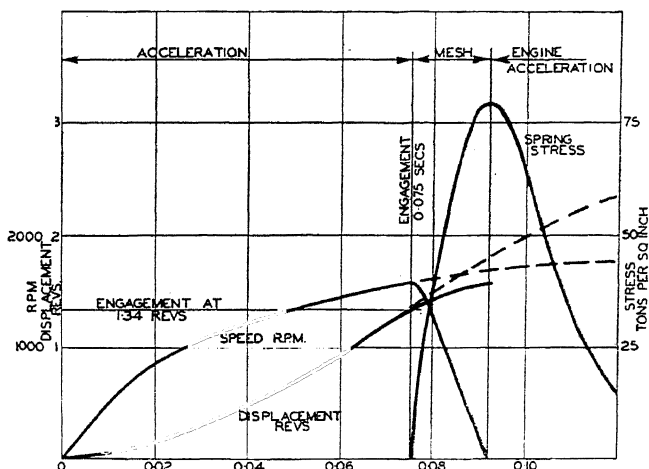

FIG. 87. MECHANICS OF STARTER-DRIVE ENGAGEMENT
(*By courtesy of the Institution of Automobile Engineers.*)

the free running armature suddenly takes up the drive, heavy stresses are set up and the engagement is necessarily noisy.

An improved inertia type starter drive with a rubber cushioning and clutch slipping member introduced by Joseph Lucas, Ltd., is shown in Fig. 88. The drive is a self-contained unit mounted on the armature shaft on which the pinion rides directly instead of being mounted on the screwed sleeve. A small pinion can thus be used giving a higher gear ratio between engine and starter, the latter operating with greater efficiency at a higher speed. The whole of the mechanism, except

the pinion, is mounted on a long sleeve on the inner end
of which is a shoulder and on the outer end a nut.
The drive from the armature shaft is transmitted
through a key to the long sleeve and through a trans-
mission plate to the outer sleeve, between which and
the inner sleeve is compressed under substantial pres-
sure, a rubber bush or coupling. The outer end of the

STARTER DRIVE TYPE RU910 SHOWING PATHS TAKEN BY DRIVING TORQUE

FIG. 88. LUCAS STARTER DRIVE

inner sleeve drives by projections, a screwed sleeve
which is in turn connected positively by teeth to a
steel washer separated from the outer sleeve by a
bronze friction washer. A control nut is mounted on
the screwed sleeve and is connected by dogs to the
pinion barrel so that the control nut, pinion barrel, and
pinion move endwise and rotate together. The pinion
restraining spring tends to draw the pinion out of
mesh.

When the starter is energized, the rotation of the
armature shaft is transmitted through the transmission
plate, the outer sleeve, the rubber coupling and the
inner sleeve to the screwed sleeve. The control nut
travels along the screwed sleeve and also rotates the

pinion barrel moving with it so that the pinion engages the teeth on the flywheel in the usual way. Should the teeth of the pinion and the teeth on the flywheel rim meet end to end, a light relief spring between the inner sleeve and the transmission plate avoids shock and allows the pinion to edge its way into gear. The inertia of the armature is taken up by, and the additional torque is transmitted through, the rubber coupling which may allow rotation through about 30°. The reaction on the screwed sleeve moves it backwards along the shaft and increases the pressure between the steel washer, friction washer, and outer sleeve, whereby additional torque is transmitted as shown by the lower dotted line. The upper dotted line shows the direction of the torque through the rubber coupling.

The rubber coupling limits the torque which may be transmitted since slipping takes place between it and the outer or inner sleeves, usually the latter, when a certain value is exceeded. Slipping does not occur under normal conditions, but only under a severe overload so that a definite limit is set to the torque which may be transmitted and the resulting stresses.

C.A.V.-Bosch Axial Starter. The C.A.V.-Bosch starter motor has been specially designed to meet the exacting requirements in the starting of heavy commercial vehicle engines. The pinion engaging mechanism is not exposed. The whole armature with the pinion moves axially to engage the pinion with the toothed ring on the engine flywheel.

A longitudinal section through the starter is shown in Fig. 89. Four laminated poles c are secured in the usual manner by screws to the cylindrical casing d, two carrying the main series field windings, while the other two carry the auxiliary shunt and series field windings a. The field windings a are divided into the main series winding, an auxiliary series winding, and
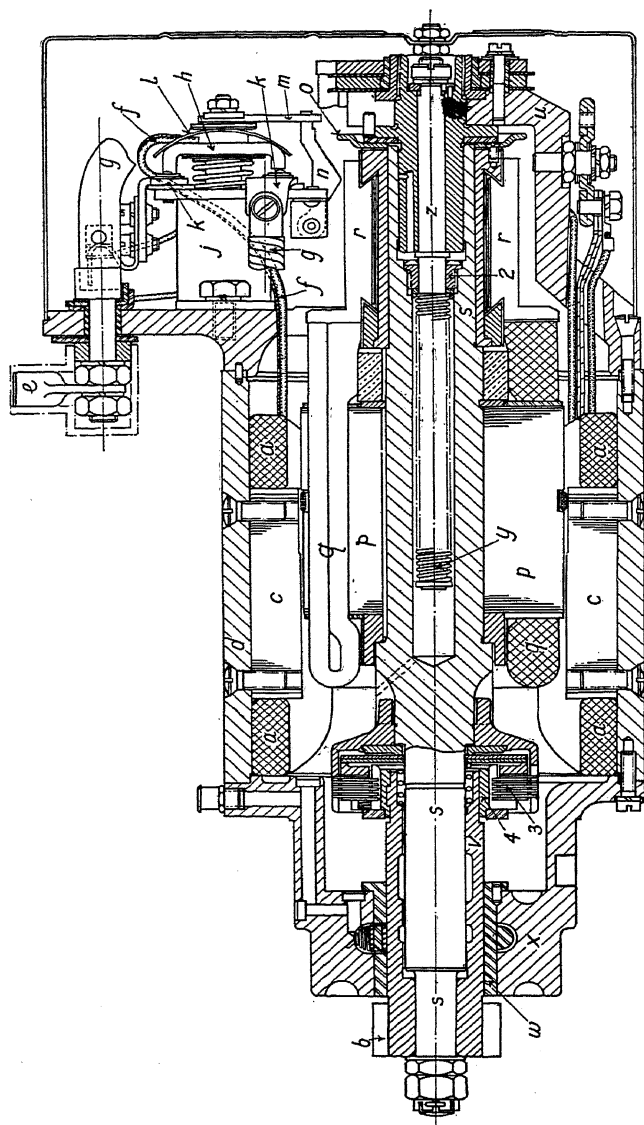
Fig. 89. C.A.V.-Bosch Axial Starter

a small shunt winding. When the main starter switch is first closed, a small current passes through the main terminal e and auxiliary leads f to the auxiliary shunt and field windings, so that the armature is rotated slowly and also pulled forward to bring the pinion b gently into mesh with the engine flywheel teeth. This forward movement of the armature also closes, through tripping mechanism, the contacts of a solenoid switch which completes the main circuit, so that current flows through the armature and the series windings, and the full torque of the motor is exerted on the engine. As soon as the engine fires, the armature is withdrawn by a spring and the pinion automatically disengages.

The trip mechanism operates as follows: When the switch is first operated, the current cannot flow through the main leads g to the windings, since the circuit is completed by a solenoid switch j, through the bridge member h, which is then held out of engagement with contacts k by a spring l, and a lever m having a slot in its end through which passes the end of a pivoted trip lever n. The shoulder on the trip lever holds the lever m and the bridge member h out of contact against the attraction of the solenoid j, which is supplied with current through an independent connection. During the latter part of the movement, the tripping disk o on the armature shaft catches a heel on the trip lever n and lifts it slightly so that the lever m is freed and the main circuit is closed by the bridge member h, which is then drawn by the solenoid j into engagement with the contacts k. The full current then flows through the main leads g to the armature and main field windings.

The armature laminations p are clamped on a shaft s running right through and supported by end bearings which permit it to slide sufficiently to allow engagement

of the pinion b. The rearmost bearing is formed
by a cylinder t carried rigidly by the frame u of the
machine and projecting into a cylindrical hole in the
end of the shaft s. On the other end of the shaft s
is mounted with freedom to rotate a bronze pinion b
integral with a tubular extension v supported in the
bearing sleeve w carried in the end cover. The com-
mutator r is also made of such a length that the brushes
always remain properly in engagement. Wear takes
place on the bronze pinion b, which may be replaced
easily, in preference to the teeth on the flywheel rim.
The armature and pinion are withdrawn by a helical
spring y, the resistance of which is overcome by the
electro-magnetic forces at starting. This spring is
mounted on a spindle z fixed in the frame member u,
one end of the spring y abutting against a collar on
the end of the spindle and the other end bearing
against a collar 2 carried by the armature shaft s.

The multiple disk clutch 3 forming the driving con-
nection between the spindle s and the sleeve v carrying
the pinion b, is actuated by axial movement of a
sleeve 4 which is mounted on the end of the sleeve v
by a fast thread having an angle of about 45°. When
the pinion b is driving the flywheel, the torque acting
through this screw thrusts the sleeve 4 to the right
and forces the disks into engagement. When the
engine fires, the pinion b and sleeve v tend to overrun
and the disks are freed. The clutch is so proportioned
that the torque which can be transmitted by it is
above the lock torque of the starter, but below the
shearing strength of the pinion teeth. The clutch thus
forms an overload device which prevents damage due
to an engine backfire.

Scintilla Starters. The starter to be first described
is used with a compression-ignition engine and is of
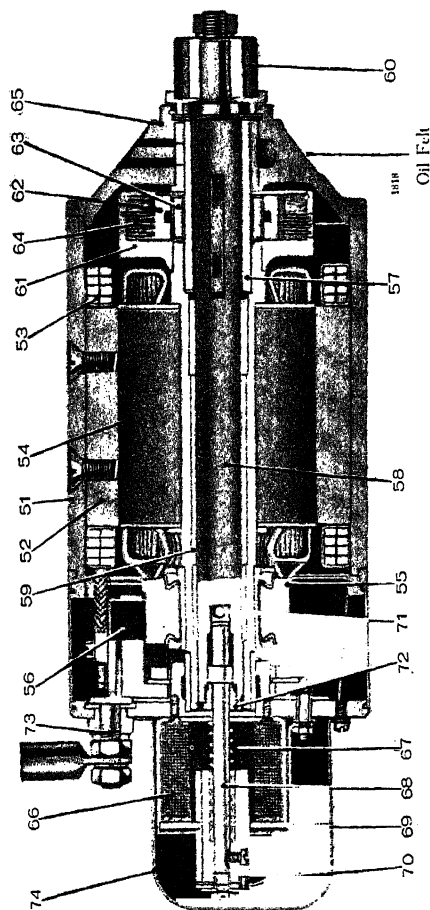the heavy duty type in which the pinion is first moved

FIG. 90. SCINTILLA STARTER MOTOR

Description of Parts

51 Carcase
52 Pole shoe
53 Field winding
54 Armature
55 Commutator
56 Carbon brushes
57 Pinion shaft bearing
58 Pinion shaft
59 Lubricating felt
60 Pinion
61 Clutch housing
62 Roller housing
63 Clutch rollers
64 Clutch plates
65 Front end plate
66 Relay coil
67 Return spring
68 Actuating rod
69 Fixed contacts
70 Laminated moving contact
71 Ball in actuating rod
72 Securing nut
73 Main terminal stud
74 Cover

Oil Felt

by an electric relay into engagement when the starting switch is operated, the full current being supplied to rotate the armature only when engagement has taken place. The first movement may be brought about directly by hand or foot control or indirectly by an electro-magnetic relay. The latter type is shown in Fig 90, and in the wiring diagram, Fig. 91, as applied to a compression-ignition engine fitted with heating plugs to assist starting.

The starter is designed to operate at 24 volts and is of the six-pole type. It is made in three sizes developing 4, 6, and 13 h.p. Some particulars of these three sizes are given in the first three columns of Table II.

TABLE II

Type	(1) 4 h.p., 24 V.	(2) 6 h.p., 24 V.	(3) 13 h.p., 24 V.	(4) 1·3 h.p., 12 V.	(5) 1·3 h.p. 6 V.
Volts	24	24	24	12	6
Speed at maximum power (r.p.m.)	1200	1500	1000	1500	1500
Current at maximum power (amperes)	400	430	1200	300	380
Battery capacity (amp./hrs.)	80	100	300	60	120
Maximum torque (lb. ft.)	62	88	150	11·6	7·2
Current at maximum torque (amperes)	700	1200	2400	550	650
Gear ratio to flywheel	1/12–1/16	1/12–1/16	1/10–1/12	—	—
Teeth on pinion	9–14	9–14	14–16	8–13	8–13
Diameter of casing (mm. and in.)	125 4·9	150 5·9	178 7	112 4·4	112 4·4
Overall length (mm. and in.)	383·5 15·1	418·5 16·5	539 21·2	—	—
Weight (lb.)	36	49½	104	19	19

Particulars of two smaller starters of very similar design operating on 6 and 12 volts are given in the fourth and fifth columns.

Referring to Fig. 90, the pinion 60 and its shaft 58 are pushed axially to effect engagement by the actuating rod 68 carrying the movable core of the electro-magnetic relay with coil 66. A spring 67 withdraws the pinion by means of securing nut 72, a ball 71 transmitting the thrust of the core. The armature 54 and
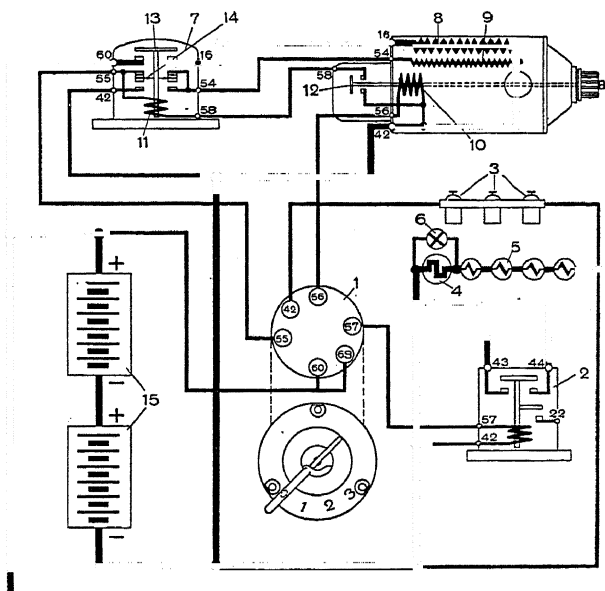
FIG. 91. SCHEMATIC DIAGRAM OF SCINTILLA STARTER WITH HEATER PLUGS

Description of Parts

1 Switchboard	9 Auxiliary field winding
2 Heater plug relay	10 Relay coil for actuating rod
3 Electric fuel lift	11 Coil for starter relay
4 Resistance for heater plugs	12 Laminated moving contact
5 Heater plugs	13 Main switch in relay
6 Control lamp for heater plugs	14 Auxiliary switch
7 Starter relay	15 Batteries, two 12-volt in series
8 Main field winding	

commutator 55 are secured to a tube which is supported at each end by plain bearings and is connected to the pinion shaft 58 by a free-wheel clutch with one way clutch rollers 63 and a friction clutch with plates 64. Only when the pinion is fully engaged, does the movable contact 70 engage fixed contact 69 to operate the starter relay closing the main circuit. Further details

can be seen on the drawing with the aid of the list of components.

Referring now to Fig. 91, when the switch key is fully inserted into the switchboard 1, terminals 68 and 42 are connected so that a circuit is closed through the electric fuel lift 3 and the battery. The locking mechanism in the switch board is also released.

To start the engine, the switch is moved in succession to positions 1, 2, 3. When it is moved to position 1, terminals 60 and 57 are connected whereby relay 2 is operated to connect contacts 43, 44, and the heater plugs 5 are supplied from the battery through resistance 4. The plugs may be of the 2-volt pattern or of other voltages such that the resistance 4 may be unnecessary. When starting from cold, the switch should be held in position 1 for from thirty to sixty seconds, according to the characteristics of the engine. The control lamp 6, which is in parallel with resistance 4, is also illuminated in this position. On moving the switch to position 2, current passes from the battery through terminal 55, across switch 14, through auxiliary field 9 and the armature and causes very slow rotation of the armature in the reverse direction. This reverse rotation brings about slip of the clutch which sets up a small amount of friction between the rollers and the pinion shaft, the friction being sufficient to rotate the pinion shaft gently and assist engagement.

In switch position 3, terminal 56 is supplied from the battery, thus energizing solenoid 10 (66 in Fig. 90) so that the pinion and its shaft are moved axially, engagement being facilitated by the fact that the pinion is still rotating slowly in the reverse direction. The teeth cannot be damaged as the only forces in operation are those due to the friction of the overrunning clutch and the rotational inertia of the pinion shaft.

The Scintilla foot-operated or mechanical engagement

starter is very similar to the electrical engagement type. Fig. 92 shows a sectional view with the pinion disengaged. When pedal 100 is depressed, levers 80, 81 are operated through compression spring 84, so that spring-loaded plunger 82 may move axially the pinion shaft 83 to which the pinion is secured. The shaft and pinion move the distance B, thus engaging toothed ring 104 on the flywheel. As soon as the pinion is fully engaged, movable contacts 85 and 86 make connection with fixed contact plates 89 and 95, thus completing the battery circuit when the full starting torque is applied.

A good connection free from arcing between contacts 85, 86, 89, 95 is ensured by suitable adjustment of the stop 101 which allows further movement of the pedal 100 after the contacts first engage, spring 84 being then compressed until the pedal engages the stop.

If the pinion teeth are not in line with the teeth on the flywheel when the pedal is depressed, special mechanism brings about a slight rotation of the pinion shaft to effect engagement. This mechanism consists of a quick thread nut 88 mounted on a quick thread bush on the end of the pinion shaft 83, rotation of the nut being resisted by braking surfaces on discs 90, 97, which are urged towards one another by springs 90. Since rotation of the nut is resisted, the pinion shaft is rotated as the discs and plunger 82 are moved forward by the pedal against springs 110. Further movement of the discs is followed by tripping of pawls 96 mounted on disc 97 when their arms engage fixed stops 113, the pawls then separating the discs so that the braking surfaces no longer engage nut 88 and pinion shaft 83 can rotate freely. Due to distance C being less than distance D, the brake assembly is free from pressure when contacts 85, 86 make connection with contact plates 89, 95. The brake mechanism not
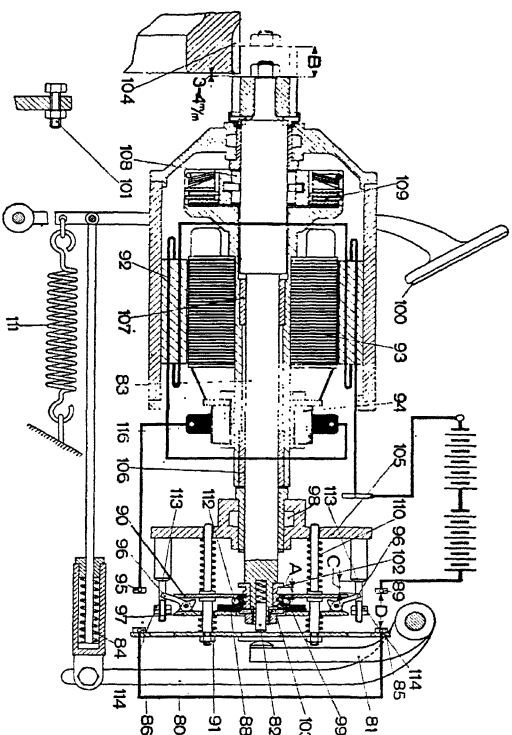
Fig. 92. Scintilla Starter with Mechanical Engagement

Description of Parts

80 Actuating lever
81 Pressure lever
82 Spring loaded plunger
83 Pinion shaft
84 Compression spring
85, 86 Moving contacts
88 Quick thread nut
89 Fixed contact
90 Disc

91 Compression spring
92 Field winding
93 Armature
94 Commutator
95 Fixed contact
96 Pawls
97 Brake disc with pawls
98 Grease housing
99 Brake lining

100 Pedal
101 Adjustable stop
102 Stop on quick thread bush
103 Quick thread bush
104 Toothed ring on flywheel
105 Bearing plate
106, 107 Bearing bushes
108 Roller clutch
109 Clutch coupling

110 Compression spring
111 Tension spring
112 Thrust bearing
113 Fixed stops for pawls
114 Adjustable stops for pawls
115 Carbon brush

only facilitates pinion engagement but brings the pinion shaft to rest quickly when pedal 100 is released, the pawls 96 being then tripped in the reverse direction by stops 114 so that the nut 88 is again held by the
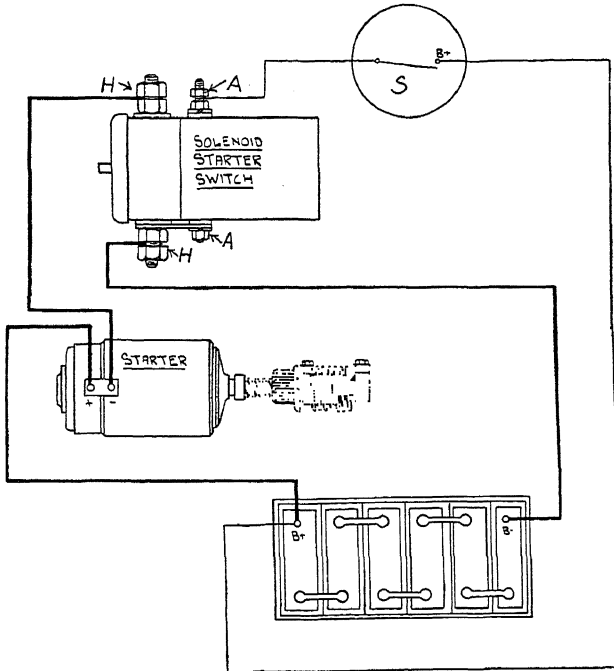

FIG. 93. M.C.L. RELAY STARTER SYSTEM

friction surfaces on discs 90, 97. The brake also prevents any movement of the pinion towards the flywheel due to road or engine vibration. Although only the usual series field windings 92 are shown, a shunt winding is also provided on some of the field poles to limit the maximum speed and prevent damage to the armature windings.

Rubber mountings are now widely used for the power unit, thereby insulating it from the frame or at any rate leaving only partial and indirect electrical connections; for instance, the petrol pipe and transmission.
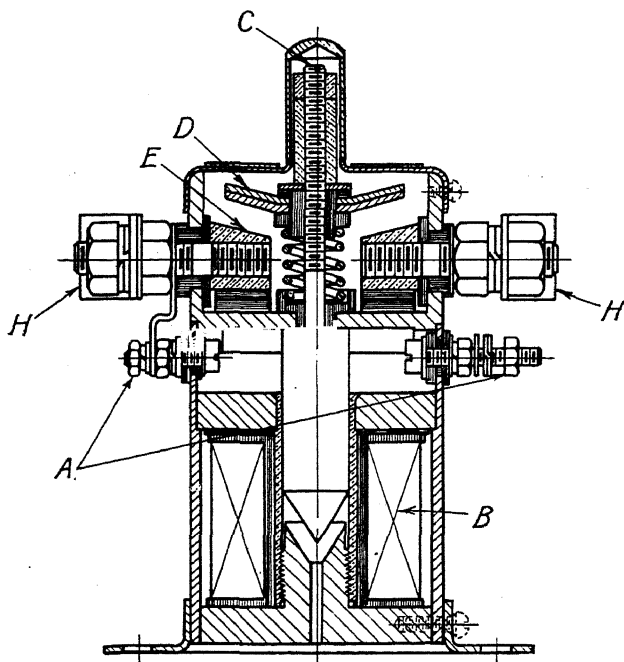

FIG. 94. M.C.L. SOLENOID STARTER SWITCH

The heavy currents required by the starter motor call for a good earth return to the frame and battery, if starting performance is not to be impaired. But apart from this the passage of electric currents through bearings disturbs the oil film seriously and may greatly increase bearing wear and the possibility of seizure.

M.C.L. Solenoid Relay Starting Switches. This may

be arranged near the battery and the starter motor and thereby reduces the length of heavy wiring. Fig. 94 shows the solenoid switch in detail and Fig. 93 the wiring diagram. The ordinary switch S, disposed within reach of the driver, closes a circuit through the shunt terminals A and solenoid B which then moves the centre spindle and plunger with contact disks D, into contact with the contact segments E connected to the main terminals H.

Scintilla Heater Plugs for compression-ignition engines, shown in Fig. 95, are of the double-pole 2-volt type, and consist essentially of a short coil of thick
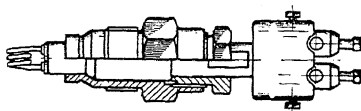

Fig. 95. Scintilla Heater Plug for C.I. E

copper wire carrying current of such value that it is heated to incandescence and assists ignition of the fuel injected at starting when the engine is cold. A series resistance is used where necessary, depending upon the voltage and the number of plugs. Heater plugs of other voltages are produced to avoid the necessity for the use of a resistance, particularly with 24-volt systems. A control lamp in series with the plugs shows whether they are in operation. If it does not light when the plugs are switched on, the terminals of each plug should be bridged in succession until the lamp lights, thus indicating which plug is at fault.

CIRCUIT DIAGRAMS

The electrical equipment on many vehicles includes a great variety of separate units which must be properly connected, the electrical relationship being shown on

wiring diagrams which are always supplied by the car makers or the suppliers of the electrical equipment.

Single and two-wire systems are employed. In the former the frame always forms the earth return from the lamps, etc., to the battery, while in the latter,
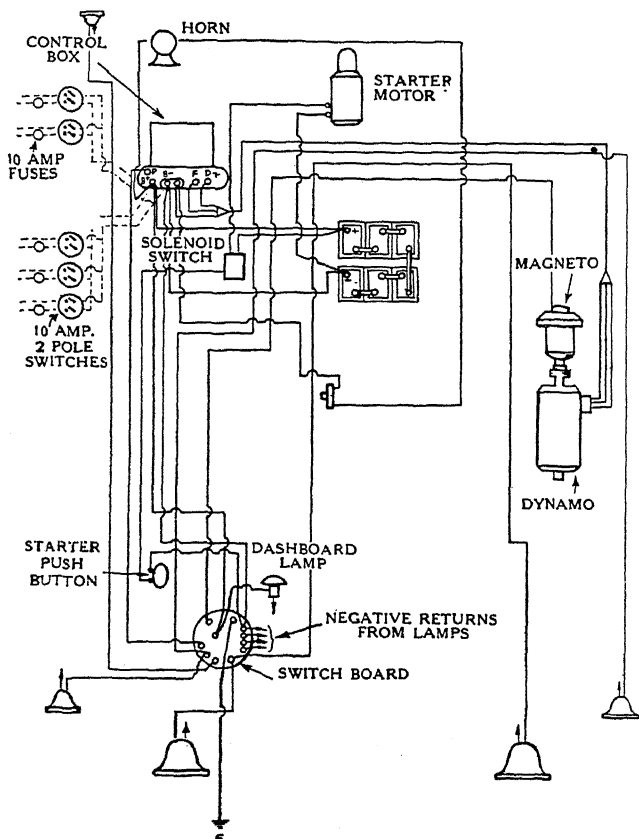

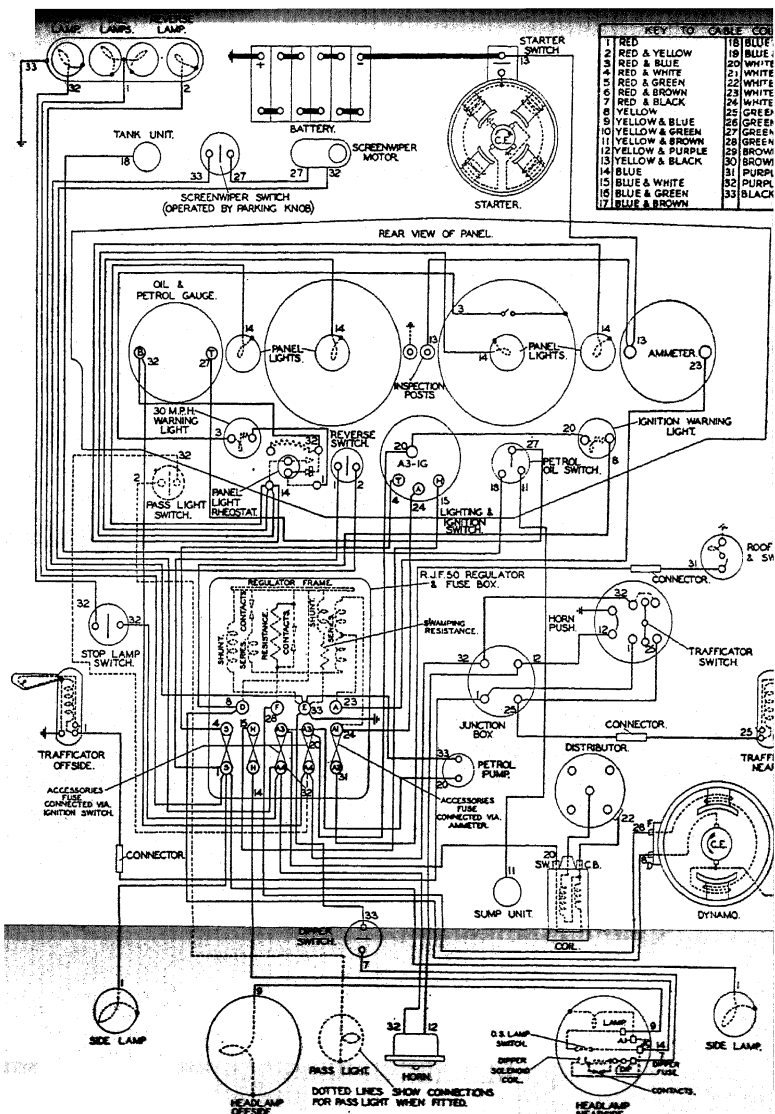FIG. 96. C.A.V.-BOSCH ELECTRICAL EQUIPMENT ON A.E.C. BUSES

FIG. 97. LUCAS ELECTRICAL SYSTEM ON M.G. CAR

separate positive and negative wires are used. The
ignition circuit is, however, always on the one-wire
or earth-return system. Also in single-wire systems,
the starter connection to the battery may be on the
two-wire system, since these leads are always specially
heavy and a short and direct path of flow is desirable.

A wiring diagram showing C.A.V.-Bosch electrical
equipment on A.E.C. buses is shown in Fig. 96.   A
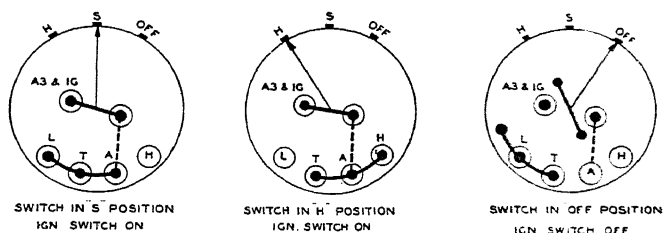two-wire system is employed, except as regards the

FIG. 98. INTERNAL CONNECTIONS OF LAMP SWITCH

magneto, the high-tension leads not being shown. Also,
the negative return wires from the lamps are not shown
completely, only their terminal connections being in-
dicated. The head, side, and tail lamps are controlled
from the switchboard, and the interior lighting con-
nections are led from the control box. The starter
push-button operates the solenoid switch which closes
the battery starter circuit.

A wiring diagram for a Lucas electrical system as
applied to a car made by the M.G. Car Company is
shown in Fig. 97, the internal connections of the lamp
switches being shown in Fig. 98. This diagram shows
the functional relationship and also something of the
internal circuits of all the components and accessories.
The wires are all coloured differently to assist in
identifying them on the vehicle, since they are as far

as possible braided together. Each wire is numbered on the diagram and a key to the numbers and corresponding colour is also given. The system is of the single-wire type with a positive earth formed by the frame of the vehicle. It is possible to trace out the circuits of all the components, current being supplied from the negative terminals of either the battery or the dynamo and led through any one or more of the components as required to earth. The following description of the circuits will assist—

The starter motor heavy gauge circuit is complete in itself, and in addition there are twenty-seven places where current, either from the battery or from the dynamo, is used. These may be divided into six groups—

1. Those which are independent of the ignition switch and protected by fuses—

The two head-lamps.
The two side-lamps.
The reverse lamp.
The two tail-lamps.
The interior lamp.

2. Those operated by the ignition switch and having no fuse protection—

The ignition.
The ignition warning-light.
The petrol pump.

3. The petrol gauge, also operated by the ignition switch but fuse protected.

4. Those which are brought into action by the ignition switch and are fuse protected, but have an automatic operating device—

The stop-lamp.
The 30 m.p.h. warning-lamp.

5. Those which have separate manual controls, but

can only be used when the ignition is switched on. They are all protected by fuses—

> The horn.
> The two trafficators.
> The oil gauge.
> The windscreen wiper.
> The four dash-lamps.

6. The inspection sockets which have an independent circuit, as they (apart from the starter motor) constitute the only circuit through which current from the battery can flow without passing through the ammeter.

The current leaves the battery negative terminal by the starter wire and returns to the positive terminal by the frame or earth connection after passing through any one or more of the components. These two wires are the only battery connections, and the negative wire to the starter carries all the current for the vehicle as well as the starter current.

From the starter switch current flows by wire 13 to the input terminal of the ammeter. From this terminal a second wire 13 carries current to one terminal of the inspection socket, and when an inspection lamp is plugged into these sockets, this circuit is completed through the other terminal to the instrument panel (earthed to the frame by the speedometer and revolution counter drive cables, etc.).

The battery may be charged in position on the car by simply plugging into these inspection sockets.

Current from the battery passing through the ammeter is led by wire 23 to terminal A on the back of the regulator box. The cut-out is shown on the left of the box and the C.V.C. on the right.

The three wires so far mentioned (excluding the diversion to the inspection sockets) together with the ammeter, form the main current connections along

which current flows one way when the battery is supplying it, and the other way when the dynamo is charging the battery.

Current from the battery passes from terminal A through part of the regulator winding to terminal $A1$ on the back of the regulator box.

Current from the negative terminal of the dynamo is led along wire 8 to terminal D on the back of the regulator box, whence it passes through the cut-out to the voltage regulator, from which it has two paths: (1) to terminal A, and (2) to terminal $A1$, both on the back of the regulator box.

Terminal $A1$ is thus constantly supplied with current either from the battery to A or from the dynamo to D—and it is from this point $A1$ that current is drawn for any of the twenty-six points (since the inspection sockets are a circuit apart) where it may be wanted. When the dynamo is working, all the current not drawn off from $A1$ passes from A along the main current connection described above to charge the battery.

A small part of the current at $A1$ (whether from battery or from dynamo) may pass through the accessories fuse to terminal $A2$ for the interior light. The rest is taken by wire 24 to terminal A on the back of the switch body to supply any, or all, of the other twenty-five points where current may be wanted.

Current for the interior light is carried by wire 31 to the roof lamp and switch.

The current which arrives at terminal A on the back of the switch body, shown also in Fig. 98, is used as required.

1. When the light switch is turned to S, terminal A is put into communication with terminal T.

2. When the light switch is turned to H, terminal A is in communication with both terminals T and H.

3. When the ignition switch is turned on, terminal *A* is put into communication with terminal *A*3-*IG*.

Current which arrives at terminal *T* is led by wire 4 to the upper of the two terminals marked *S* on the back of the regulator box. Thence through the fuse *S*-*S* to the lower terminal *S*. To this terminal four wires (1) lead—

> One to each side-lamp.
> One to the two tail-lamps.
> One to the reverse lamp switch.

The side-lamp circuits are completed through the bulbs to the lamp bodies, thence by the wing supports to the frame.

The tail-lamp wire leads to the off-side and near-side tail-lamp bulbs, which are earthed through the number plate casing to the frame.

The reverse light can only be switched on when the side-lamps are on. Current is then led through reverse switch and wire 2 to the reverse lamp and thence to the number plate casing and frame.

When the light switch is turned to *H*, terminal *A* on the switch body is connected with terminal *H* as well as terminal *T*. From this terminal *H*, wire 15 leads to the upper terminal *H* on the regulator box, thence through a fuse to the lower terminal *H* and by wire 14 to terminal *A*1 inside the near-side lamp body where it divides as follows—

1. Through the near-side head-lamp filament to the lamp body and earth.

2. Along one of three paths, according to whether the head-lamps are (*a*) full on, (*b*) in the act of dipping, (*c*) dipped.

> (*a*) When the dipping switch is open, current passes through the off-side lamp switch, which is inside the near-side head-lamp, to the terminal

marked "lamp," from which it is led by wire 9 to the off-side head lamp filament and thence to earth.

(*b*) When the dipping switch is closed, current also passes through the dipper solenoid, the dipper solenoid contacts, and the dipper fuse to the terminal marked "dip" (all of which are inside the near-side head-lamp body). From this terminal the current is led by wire 7 to the dipper switch. Also connected to the dipper switch is wire 33 leading to terminal *E* and earth. The flow of current along this path magnetizes the solenoid and so dips the near-side head-lamp reflector.

(*c*) As soon as the reflector is dipped, it opens the off-side lamp switch (so that no current now goes to the off-side head lamp), and also the dipper solenoid contacts, thus inserting the dipper solenoid resistance in series with the dipper solenoid. The reduced or holding current which now flows through the dipper solenoid is only enough to hold it in its dipped position.

When the dipping switch is again opened, no current can flow through the dipper solenoid and the reflector therefore springs back to its undipped position and again switches on the off-side head-lamp.

On the terminal *A*3— *IG* on the back of the switch body, are two wires 20, one leading to the ignition warning-light, and the other to one of the two terminals *A*3 on the back of the regulator box.

The ignition warning-light current flows through the filament and wire 8 to terminal *D* on the regulator box, and thence by another wire 8 to terminal *B* on the dynamo, and the dynamo windings to earth.

As soon as the dynamo has reached a sufficient output in opposition to the battery to close the cut-out points, the terminals *D* and *A*1 (one on each side of the ignition warning-lamp) are connected at the same

voltage, so that no current can pass through the filament. The current which arrives at the terminals $A3$ on the regulator box from either the battery or the dynamo through ignition switch contact $A3—IG$ divides as follows—

Along two wires 20 leading respectively to the coil and the petrol pump.

Through two fuses to terminals $A4$.

One wire 20 leads current to coil terminal SW and thence through the primary winding out through terminal CB and by wire 22 to the contact-breaker, and so through the points, when they are closed, to earth. The other wire 20 takes current to one terminal of the petrol pump, the other terminal being connected through terminal E of the regulator box to earth. Terminal E serves as a combined earth to a number of circuits.

The five wires connected to terminals $A4$ lead to the stop-lamp, windscreen wiper, petrol gauge, trafficators, and horn.

These wires are all numbered 32, and the only one that can be distinguished is the horn wire which is very much larger than the others.

The fuse between left-hand contacts $A3$, $A4$, protects the horn, stop-lamp, and windscreen wiper. From the left terminal $A4$, wire 32 supplies current to the horn and thence through wire 12 to the junction box, horn push, and earth, so that the horn is sounded when the horn push closes the circuit.

Another wire 32 supplies the stop-lamp switch and the stop-lamp, the switch being closed by movement of the brake pedal to apply the brakes. This circuit is completed through the lamp bulb and the number-plate casing to earth.

The third wire 32 leads direct to the windscreen wiper, and the current returns by wire 27 through the

windscreen wiper switch, when the switch is closed, and wire 33 to the earth terminal E.

The fuse between the right-hand terminals $A3, A4$ protects the petrol and oil gauge, the 30 m.p.h. warning-light, the four panel lights, and the two trafficators.

From right-hand terminal $A4$, current passes by one wire 32 to terminal B of the petrol-oil gauge. Inside the petrol-oil gauge the current used for level indication divides. Part is earthed by way of a solenoid which tends to pull the indicating hand towards "full." The other part leads to terminal T on the gauge through another winding which tends to pull the indicating hand back towards "empty." The current flows from terminal T by wire 27 to the middle terminal of the petrol-oil switch and normally leaves this switch by wire 18 leading to the tank unit, where it passes through more or less of the windings of the rheostat contained in this unit (according to the level of the float in the tank) to earth.

When the petrol-oil switch button is pressed, the connection to wire 18 is broken, and the current is led through wire 11 to the sump unit, and so through more or less of the windings of the corresponding rheostat (according to the level of the float in the sump) to the metal of the sump and earth.

Terminal B on the oil and petrol gauge acts as a junction post, for to it is connected a second wire 32 which leads current to the panel-light rheostat controlling the 30 m.p.h. warning-lamp and the four panel-lights. This rheostat has two copper fingers, the lower being always in contact with the resistance coils and carrying the current for the 30 m.p.h. warning-light. From this finger, current passes by wire 1 to the warning-light and thence by wire 3 to the speedometer and, when the car is doing between 20 and 30 m.p.h., through a switch inside the speedometer to earth.

When the upper copper finger of the panel-light rheostat is brought into contact with the resistance coils, it carries current to the four wires 14 which lead to the four panel-light filaments, and thence to earth. As the finger is moved farther in an anti-clockwise direction, resistance is progressively introduced into the panel-light circuits, thus dimming the panel lights and also the 30 m.p.h. warning-light.

One of the wires 32 from lower terminal $A4$ leads to one of the posts in the junction box. From the same post another wire 32 takes current to the trafficator control switch. When this switch is turned to the left, the current is carried by wire 25 through a connection in the junction box to the near-side trafficator, and when the switch is turned to the right the current is similarly led by wires 1 to the off-side trafficator.

When the change gear lever is moved into reverse, the reverse switch is closed to supply current to the reverse lamp, but this circuit can only be energized when the lighting and ignition switch has been operated to supply current to the side- and tail-lamps.

The pass light or fog light when fitted, is arranged in front of the vehicle and is supplied from lower terminal $A4$ through the connections shown in dotted lines.

The earth return in single-wire systems was at one time always negative, but in many single-wire systems used to-day this has been reversed since a positive earth return causes reduced electrolytic action and consequent corrosion of the battery terminals.

BATTERIES

Lead-acid Type. A battery or accumulator forms one of the essential components of a complete motor vehicle electrical system and at the same time is one of the most delicate.

With the lead-acid type, which is in most general use, attention is necessary to prevent an excessive consumption of current when starting, to avoid the accumulator becoming too far discharged and to keep the plates covered by the electrolyte. To provide safeguards which will avoid misuse of the accumulator is the object of the designer, but personal attention by the user is still necessary if effective performance and reasonably long life are to be obtained. Questions of cost and weight often limit the efficiency of the accumulator supplied by the manufacturers with cars of light or medium weight, but with the heavier commercial vehicles, particularly those used for passenger services, continual and reliable service for long periods and mileages is of more importance than first cost. In such cases larger and more efficient, though necessarily more expensive, accumulators can be used.

In ordinary motor vehicles the accumulator may have to supply a steady current of from 5 to 15 amps. when the engine is not charging. For starting, very heavy currents are required for short periods, the amperage then being in the neighbourhood of 100 to 300, depending on whether a 6 volt or 12 volt battery is provided, the size of the starting motor, and the resistance of the engine. The lighting and ignition requirements are easily met, but the heavy starting currents call for large plate areas which are obtained by making the plates fairly thin, for instance, $\frac{3}{32}$ in. Thin plates, have, however, a shorter life than thick plates, so that the latter are generally only used on the larger more expensive vehicles, since the whole battery is heavier, takes up more room, and is more expensive.

The ordinary lead-acid accumulator provides a voltage of 6 volts with 3 cells or of 12 volts with 6 cells, the voltage obtainable from each cell being from 2 to

2·2 volts, according to its condition of charge. For heavy commercial vehicles, particularly when Diesel engined, 24 volts are increasingly used. Each cell consists essentially of a positive and a negative plate. The capacity or amperage obtainable safely depends broadly upon the total area of the plates in each cell.
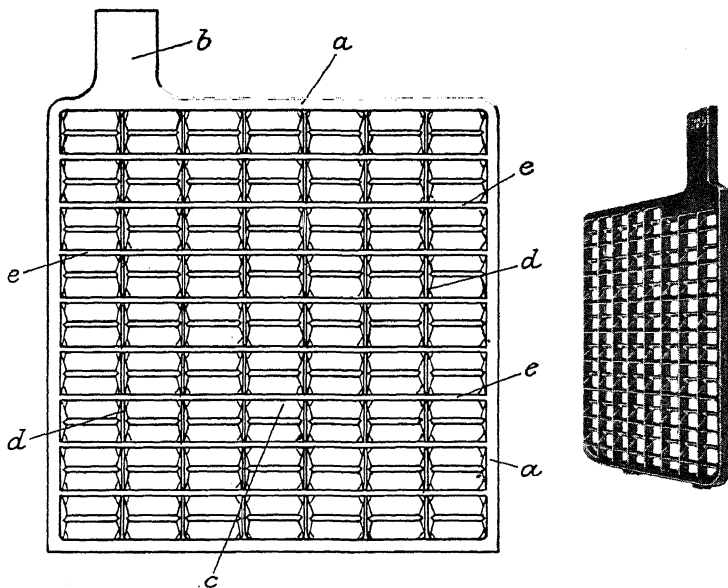

Fig. 99. Lead Grid

Charging and discharging are accompanied by certain definite chemical changes in the lead of the plates, the lead compounds associated therewith, and the dilute sulphuric acid forming the electrolyte. The oxide of lead forming the active material is held securely in a supporting framework or grid made of antimonial lead, containing usually from 5 to 10 per cent of antimony. This alloy is stronger than lead, and while providing

good electrical conductivity is not affected by the action of the electrolyte.

A grid suitable for either a positive or negative plate is shown in Fig. 99. It is diecast with a strong outer rim a having a connector lug b and enclosing
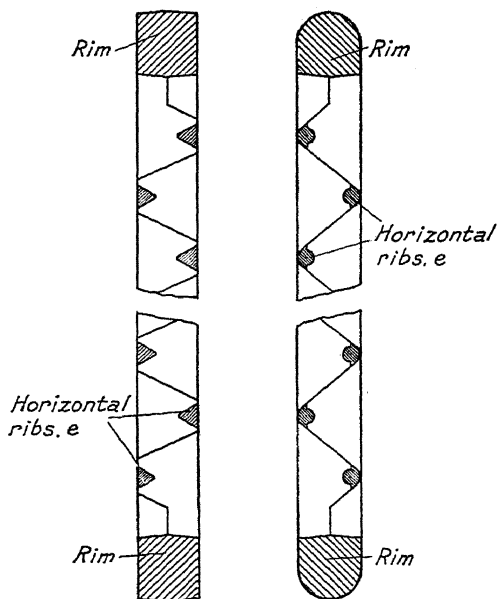
FIG. 100.   LEAD GRIDS

a network of horizontal and vertical ribs e, d, the horizontal ribs being disposed on opposite sides of the plate as shown in Fig. 100, so that the paste may run continuously from top to bottom; the vertical ribs stiffen the horizontal ribs and serve to conduct the electricity to the connector lug.

The positive plates are more affected by the electro-chemical actions which take place during charge and

discharge than the negative plates; special attention is therefore in some constructions given to their design, and the number of negative plates always exceeds the number of positive plates by one so as to avoid buckling and to ensure the even working of both sides of each positive plate.
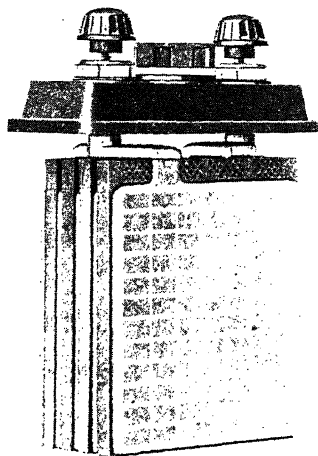
FIG. 101. GROUP OF PLATES FOR ONE CELL

Each group of either positive or negative plates is connected by a bar, which also provides a support for the terminal. The plates are properly spaced in a burning jig and the bar, which is made of antimonial lead, is burnt on to the connector lugs.

A group of two positive and three negative plates is shown in Fig. 101, assembled with separators between adjacent plates. The thickness of the separators and hence the spacing of the plates affects: (1) the quantity

of acid actively disposed between the plates; and (2) the internal resistance of the cell. These two requirements are antagonistic, since sufficient acid must be present between the plates to ensure the proper electrochemical action, while they should be as close together as possible to reduce the internal resistance. Low internal resistance is essential in motor-car accumulators which must at times provide a very heavy starting
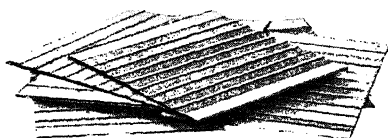
FIG. 102. WOOD SEPARATORS

current. A compromise between these two requirements may be obtained by making the space slightly more than the thickness of the positive plates. Internal resistance is also reduced by increasing the total surface area of the plates.

The positive and negative plates must be prevented from bending or buckling, otherwise they might touch one another and cause a short circuit and rapid discharge. In some designs, the plates are spaced apart by holding their edges in grooves, but this method is only satisfactory with specially rigid plates for the conditions of use on motor vehicles, where the accumulators are subject to continual and often violent movement and space is limited. For this reason nonconducting separators are usually arranged between the adjacent positive and negative plates.

The material of the separators must not be sensitive to the action of the electrolyte and must, while acting as an insulator, be sufficiently porous to allow diffusion of the acid. Certain kinds of wood specially treated and grooved on one or both sides have been widely

used as separators. An example is shown in Fig. 102. The separators must be slightly less in thickness than the space into which they fit, so that they may be easily slipped into position between the plates. The grooves in the plates are made as wide as possible to facilitate the free circulation of the acid over the surface of the active material. A horizontal section through a series of negative and positive plates assembled with
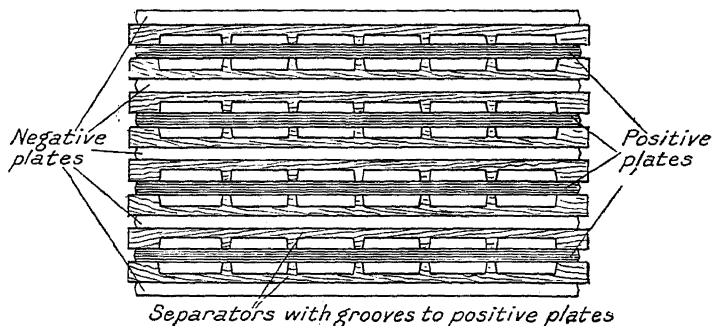

Separators with grooves to positive plates

FIG. 103. HORIZONTAL SECTION OF CELL

grooved wood separators between them is shown in Fig. 103. The grooved sides are arranged adjacent to the positive plates to provide free circulation of acid where the greatest electro-chemical activity prevails. Additional support may be provided for the paste by the insertion of a very thin sheet of perforated ebonite between the paste and the separator. Ribbed or crinkled and perforated ebonite separators may be used instead of wood separators.

Another form of plate separator which has proved very effective in practice in heavy duty accumulators is the C.A.V. threaded rubber separator which is un-affected by the acid or by moisture or dryness, a point of importance when accumulators are kept in stock for long periods in a dry condition before being

filled with electrolyte and charged. Each rubber sheet is slightly corrugated with thickened spacing ribs providing gas channels. The rubber is pierced transversely
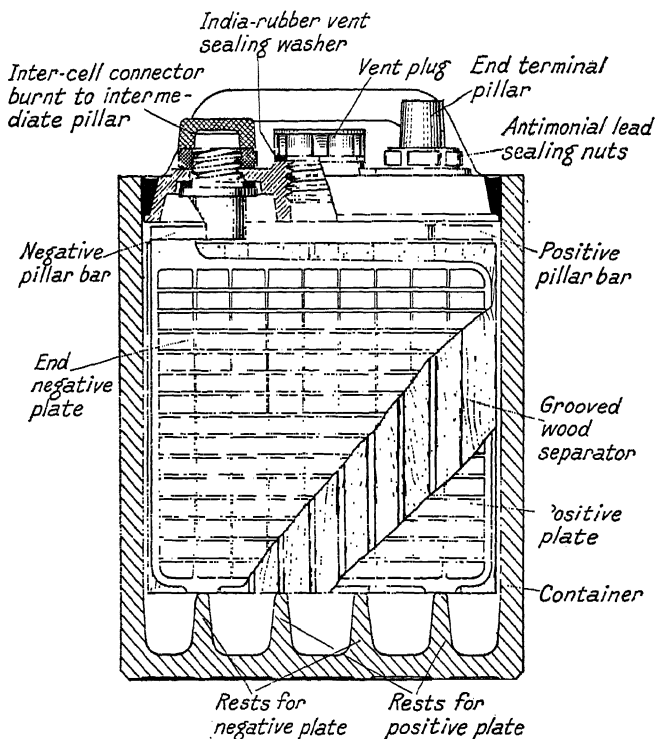

FIG. 104. VERTICAL SECTION OF CELL

by innumerable short cotton threads which maintain continuity of the electrolyte between the positive and negative plates.

Fig. 104 shows a section through an accumulator parallel to the plates, and Fig. 105 shows in detail

how either the standard conical positive or negative terminal is led from the connecting bar through the cover in an airtight manner. Handles are also moulded integral with the container. The containers are moulded from ebonite, dagenite, or similar composition, one for each cell. A moulded lid or cover of similar material
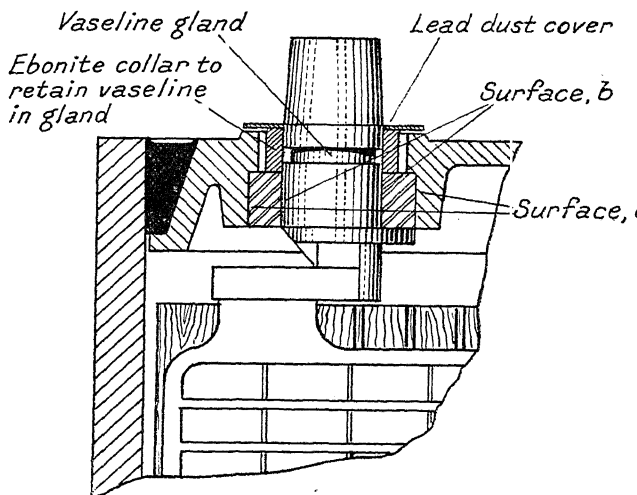
FIG. 105. TERMINAL CONSTRUCTION

is usually provided and is secured by bolts and nuts. Both the positive and negative plates are supported on rests projecting well up from the bottom of the container, so as to provide ample sediment wells for any dislodged particles of paste which can fall clear of the plates and therefore cannot bring about a short circuit. The positive and negative plates are supported by different rests, so that no short circuiting can take place should the tops of the rests be covered with sediment.

12—(T.8756)

In the terminal construction of Fig. 105, soft rubber gaskets are compressed permanently so as to make a

Melted-in lead

Inter cell connector

Lead bush moulded into cell lid

Moulded cell lid
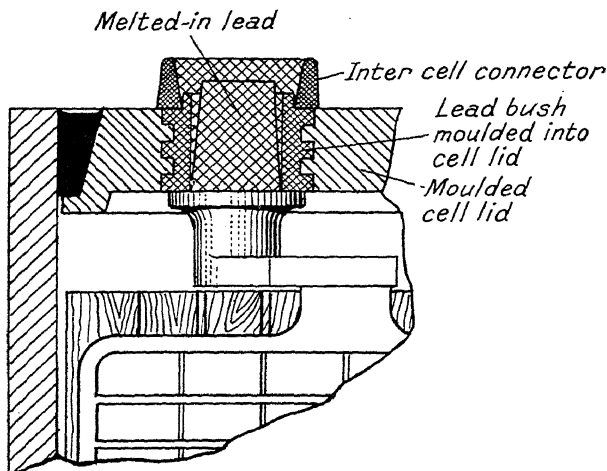
FIG. 106. TERMINAL FOR INTER-CELL CONNECTOR

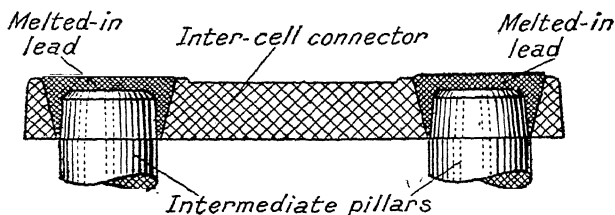tight joint with the surfaces a, b, and at the same time cushion any tendency of the bar and its connected

Melted-in lead

Inter-cell connector

Melted-in lead

Intermediate pillars

FIG. 107. INTER-CELL CONNECTOR

plates to rise. An alternative method of leading the connection from a cell through the lid is shown in Fig. 106, the terminal in this case being adapted to receive the ends of the inter-cell connectors, Fig. 107.

The lid of each cell is so shaped as to form a trough round its edge into which a sealing compound is poured, pitch or similar material being usually employed to effect an airtight closure.

The positive plates are filled with a paste of red lead (lead tetra-oxide Pb_3O_4) and the negative plates with a paste of litharge (lead monoxide PbO). There are, however, certain minor variations, other ingredients being added in small quantities according to each manufacturer's special formula. The oxides in a thin powder form are first thoroughly mixed dry and are then made into a paste with a liquid consisting of sulphuric acid and distilled water. The paste is worked well into the grid and both faces finished smooth with a rubber squeegee. The plates are then dried very slowly so as to avoid cracks, being first subjected to a damp heat and later to a dry heat. The lead of the plates co-operates to some extent with the active material during charge and discharge.

After the plates have been grouped to constitute cells, and the cells have been assembled to form the complete accumulator, further preparation known as forming the plates is necessary before they are ready for use. The chemical composition of the active material is then changed, and although other electro-chemical changes occur during charge and discharge, it never returns to its original condition. The life and the efficiency of the accumulator largely depend upon the manner in which this forming or first charging is carried out. The process consists broadly in charging the accumulator slowly after it has been filled up with the electrolyte, consisting of dilute sulphuric acid, so as to cover the plates with a margin of $\frac{1}{4}$ in. to $\frac{1}{2}$ in. The red lead on the positive plate then becomes lead peroxide (PbO_2) by the absorption of oxygen, and is of a brown colour. The lead monoxide on the negative

plate is reduced to metallic lead in a spongy or porous form when the accumulator is fully charged. During discharge, the composition of the active material on the positive and negative plates changes until both are substantially all composed of lead monoxide (PbO).

This is as far as the discharge action should ordinarily be taken, but a further discharge may occur when sulphation takes place: that is, lead sulphate is formed on both positive and negative plates. Little harm results provided that the discharge is not carried too far, and that the accumulator is recharged without delay; but if left, the sulphate consolidates and seals so that the plates become clogged up and the acid cannot approach the active material. The damage is partly mechanical, due to the growth of large crystals which deform the plates and break up the active material.

The life of a battery is certainly less than 200 cycles of charge and discharge, including sulphation, but since a battery is rarely completely discharged in ordinary use, the actual life is longer than this figure would suggest. Variation of this method, such as partial charge and discharge before charging fully, is sometimes recommended.

The voltage of the ordinary lead-acid accumulator remains substantially constant throughout the greater part of its discharge period, after which it falls more rapidly. Referring to the curves shown in Fig. 108, an accumulator can be considered to be discharged as soon as the voltage per cell drops to about 1·8. In the upper diagram, a number of curves show how the voltage decreases at different discharge rates. In each case the voltage at the beginning is about 2, but when the charging rate is high it decreases much more rapidly. The upper diagram refers to discharge rates such as are imposed by the use of the lights on a car, while the lower diagram refers to much higher
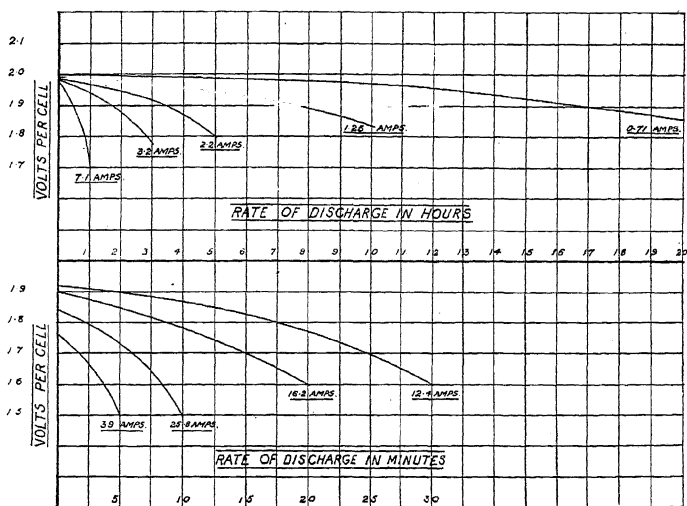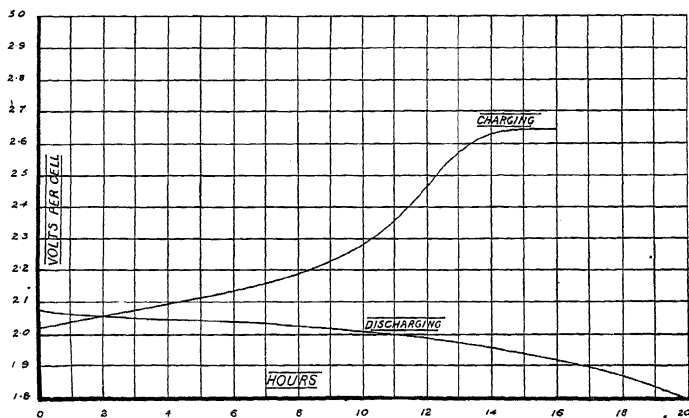
FIG. 108. VOLTAGE AND DISCHARGE RATES

FIG. 109. CHARGE AND DISCHARGE CURVES

rates per cell in accordance broadly with the demands of the starter. In the former case the period of usefulness is reckoned in hours, and in the latter case in minutes. Under ordinary conditions the charging and discharging periods occur close together, so that the accumulator should never approach the discharged state.
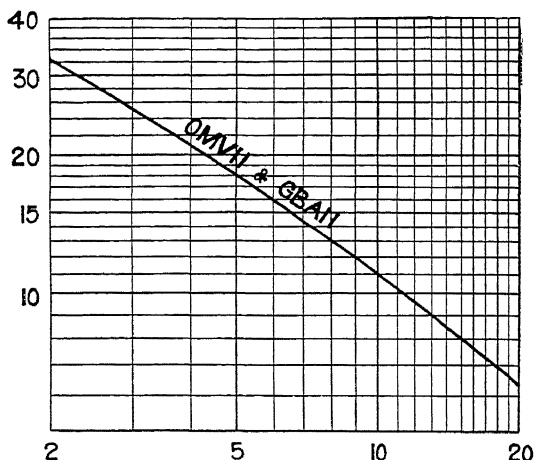

FIG. 110. DISCHARGE RATES (AMPERES) AND CORRESPONDING DISCHARGE PERIODS (HOURS)

Fig. 109 shows typical charge and discharge curves for a single cell. During charging the voltage rises steadily to a maximum of about 2·6 per cell. When charging ceases, the voltage drops rapidly to about 2·2 and still further when discharge commences.

The capacity of an accumulator is usually expressed in ampere-hours, but this is not an exact and simple standard of performance, since the product of amperage and hours before the accumulator is discharged is not constant for any accumulator.

Discharge rates measured vertically and times of discharge in hours measured horizontally are shown in Fig.

110, in connection with an Exide commercial vehicle accumulator made by the Chloride Electrical Storage Company Limited. The discharge period lengthens rapidly as the discharge current in amperes is reduced, the capacity as expressed in ampere-hours being much greater with low rates of discharge. The types of
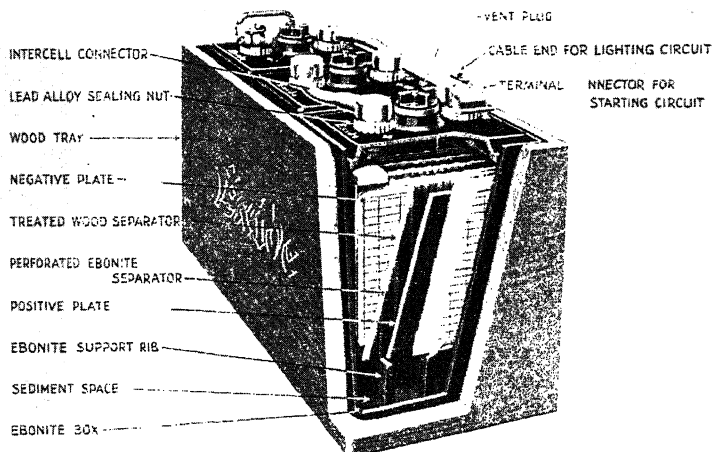

INTERCELL CONNECTOR

LEAD ALLOY SEALING NUT

WOOD TRAY

NEGATIVE PLATE

TREATED WOOD SEPARATOR

PERFORATED EBONITE
        SEPARATOR

POSITIVE PLATE

EBONITE SUPPORT RIB

SEDIMENT SPACE

EBONITE BOX

VENT PLUG

CABLE END FOR LIGHTING CIRCUIT

TERMINAL   NNECTOR FOR
                    STARTING CIRCUIT

FIG. 111. EXIDE FLAT-PLATE BATTERY

accumulator to which these figures apply are stated to have a normal capacity of 110 ampere-hours, this normal capacity being measured at the ten-hour rate of discharge, that is, 11 amperes.

An Exide 6-volt heavy-duty flat-plate accumulator is shown in Fig. 111 with one cell cut away, while Fig. 112 shows an horizontal section through a positive plate, two negative plates and the separators. In this construction the wood separators are grooved on both
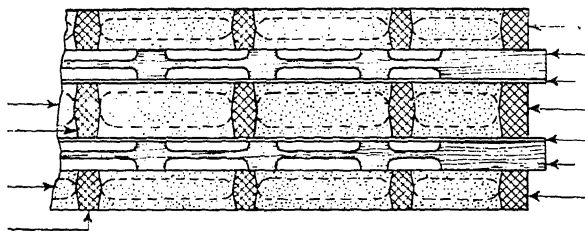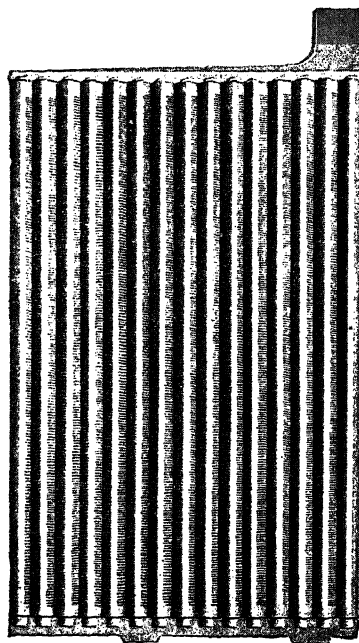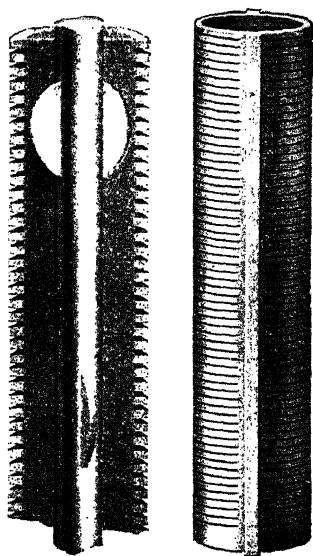
FIG. 112. EXIDE FLAT PLATES

FIG. 113. EXIDE IRONCLAD
POSITIVE PLATE

FIG. 114. EXIDE IRONCLAD
EBONITE TUBES

sides, and thin perforated ebonite separators are also employed in addition.

The Exide Ironclad method of accumulator construction is designed to ensure that under the most strenuous conditions of vibration the accumulator will maintain its capacity and give a long trouble-free life. The leading characteristic is the unusual construction of the positive plates, each of which consists of a number of vertical tubes of ebonite, shown in Fig. 113,
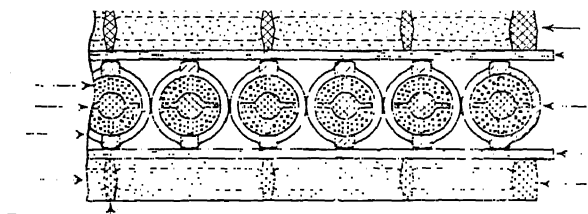
FIG. 115. EXIDE IRONCLAD PLATES

each of the seven tubes having a large number of horizontal slits which allow free access of the electrolyte to the active material contained in the tube in contact with the lead core, details of each tube being shown in Fig. 114. The negative plates are of the ordinary Exide construction but of increased thickness, a horizontal section through a positive and two negative plates being shown in Fig. 115. A part sectional view through a single cell constructed on this principle is shown in Fig. 116.

Every cell in an accumulator must be provided with a vent plug to allow the escape of gas freely and to facilitate filling of the cells; the constructions shown in Fig. 117 reduce the possibility of loss of electrolyte by splashing to a minimum. The vent plugs may be screwed in or may be secured by a quickly detachable bayonet connection.

EBONITE PLUG

LEAD COVERED
TERMINAL SCREW

LEAD ALLOY
SEALING NUT

LEAD ALLOY
PLATE STRAP

ACID LEVEL INDICATOR

POSITIVE PLATE

SLITTED EBONITE TUBE

LEAD ALLOY SPINE

NEGATIVE PLATE

NEGATIVE GRID

TREATED WOOD
SEPARATOR
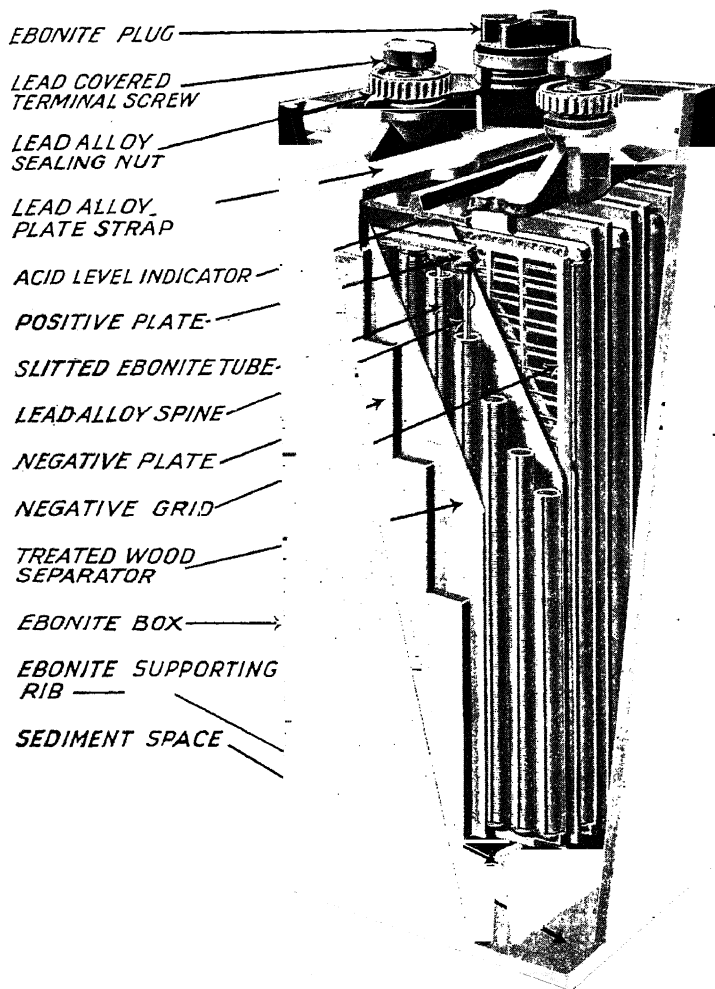
EBONITE BOX

EBONITE SUPPORTING
RIB

SEDIMENT SPACE

FIG. 116. EXIDE IRONCLAD ACCUMULATOR

Although, as mentioned previously, the voltage of an accumulator varies slightly, it is not a reliable indication of the state of charge or discharge. This can only be determined with any certainty by the aid of a hydrometer. An accumulator when fully charged should have a specific gravity of between 1·285 and 1·300, and when fully discharged it should be 1·150. In some cases accumulators are intended to work at
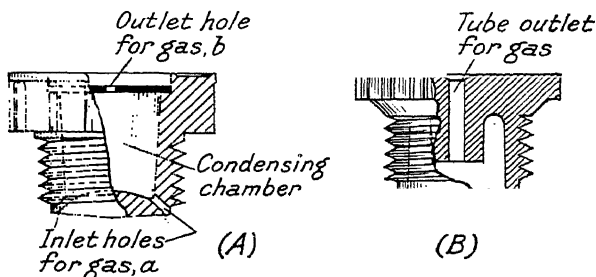
Fig. 117. VENT PLUGS

a rather lower maximum specific gravity when fully charged, this maximum being of the order of 1·250. The specific gravity is measured quite readily with the well-known siphon type of hydrometer in which the hydrometer proper is enclosed in an outer transparent container with a rubber bulb into which a sample of electrolyte may be drawn up by suction.

Only part of the electrical energy which is supplied to an accumulator is subsequently available. The term efficiency may be used in this connection—

$$\text{Efficiency} = \frac{\text{Energy available}}{\text{Energy supplied}}$$

The efficiency is of the order of 70 per cent.

In a recent type of battery made by Joseph Lucas, Ltd., shown in Fig. 118, the most apparent difference is the absence of the familiar external inter-cell

connecting links, the only parts visible above the top of the battery being the positive and negative terminals and the filler plugs. Apart from the cleaner and smoother appearance, the accumulation of dirt or moisture is less likely, and the possibility of current
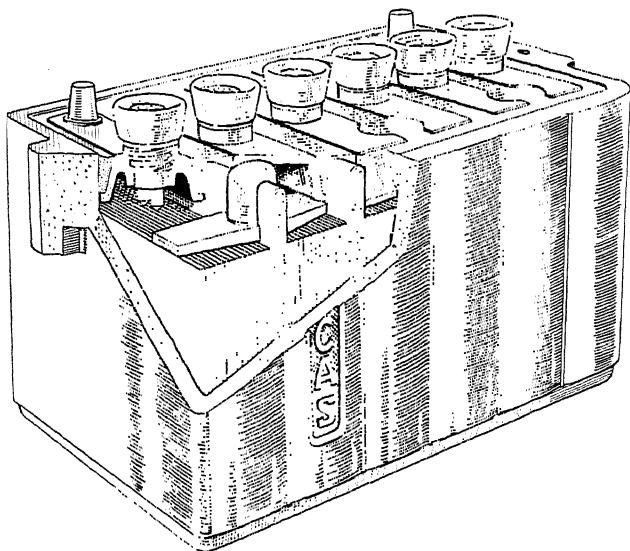

Fig. 118. Lucas Battery

leakage across the top of the battery or from one of the terminals to the chassis is reduced. Further, the risk of short-circuiting individual cells is reduced in the absence of external connectors. It will be seen from the drawing that the cells are separated by internal partitions integral with the moulded container, the adjacent cells being electrically connected by a heavy inverted U-connection straddling the partition. The cover and sealing compound come right down to the tops of the inter-cell partition and the

connectors thus completely sealing adjacent cells from one another.

Filler Cup. The battery just described can be fitted with filler cups serving also as vent plug and prismatic acid level indicator, the detailed construction being
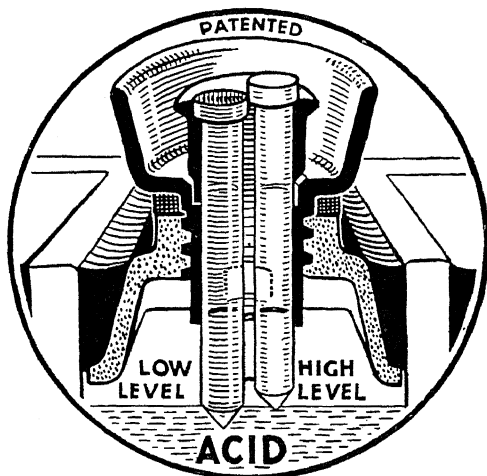

FIG. 119. LUCAS FILLER CUP

shown in Fig. 119. This device shows by means of reflecting surfaces without removing the vent plug, whether the acid is more or less at the correct level. Normally, the lower indicator will be immersed in the acid and will remain dull, while the higher indicator reflects light from the acid surface and emits a distinct and unmistakable glow even in a bad light. If the low level indicator glows also, the acid level is too low, and "topping up" is necessary. Distilled water is added until both indicators are dark. The funnel shape of the vent plug enables "topping up" to be carried out without removing the plug.

C.A.V.-Bosch Armoured Plate Battery. The positive plates in this battery have been specially strengthened to deal with heavy commercial requirements. The lead
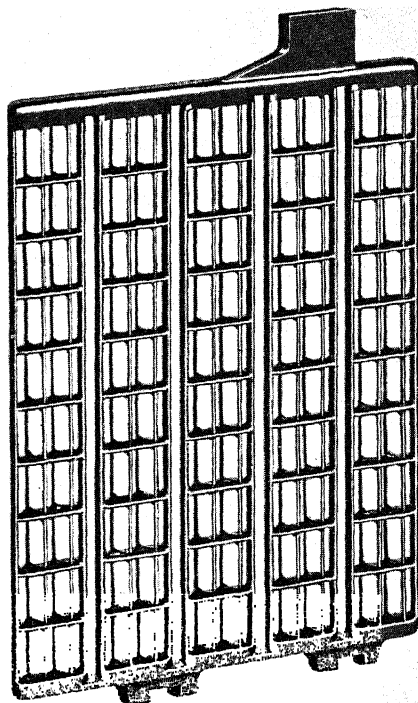

FIG. 120. UNPASTED POSITIVE PLATE GRID OF A C.A.V.
ARMOURED PLATE BATTERY

skeleton is of special construction and the active material is held in place by perforated ebonite sheaths surrounding each plate finger and allowing free access and diffusion of the acid. The antimonial lead grid

forming the backbone of the plate is shown in Fig. 120 and a sectional view is shown in Fig. 121. The grid as shown is formed from five relatively narrow vertical
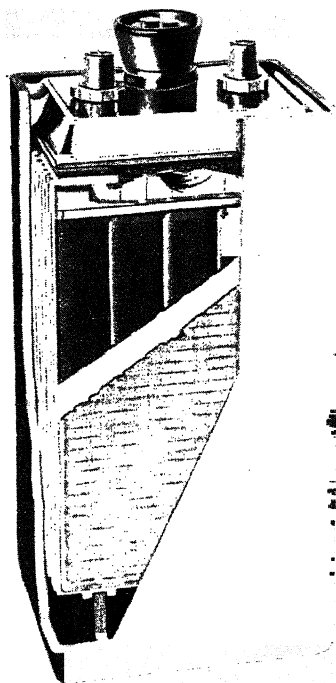

FIG. 121. C.A.V. BOSCH BATTERY

fingers securely burned to the upper and lower horizontal bars. Each strip or finger is thus practically independent of the other, and is free to move under buckling and other stresses, so that the risk of distortional damage to the plate structure is reduced to a minimum.

Each separate finger has six vertical splines, with interconnecting horizontal bars forming a robust skeleton and ensuring contact between the metal and the active material. This ensures good conductivity and reduces the internal resistance of the battery, thus facilitating heavy discharges without excessive voltage drop. Each of the five fingers is covered on each side with a shrunk-on perforated ebonite sheath, and the plates are provided with notches on all the feet which engage the ribs moulded in the bottom of the container, leaving an adequate sediment space below them. The negative plates are of standard flat construction, the general design and thickness being such that the life of the negative and positive plates will be substantially the same. The positive and negative plates are separated from each other, in addition to the ebonite sheaths, by separators of cedarwood grooved on one side to permit free circulation of the acid and chemically treated. A splash plate of perforated ebonite is fitted in each cell on top of the battery plate assembly and immediately below the vent plug holes, to prevent splashing of the electrolyte during abnormal jolting or rolling of the vehicle.

Alkaline Accumulators. The defects of the lead acid cell as a means of accumulating and giving out electrical energy have led to various attempts to find simpler, lighter, and more reliable alternatives, and the alkaline cell has been developed as a result.

There are at the present day only two types of alkaline accumulator in commercial production. One is the nickel iron type, also known as the Edison type, and the other the nickel cadmium type. The construction of the two is very similar, but there are certain differences in the material employed.

In both types the active material is enclosed in very finely perforated steel tubes or pockets, a number

of these pockets being assembled in steel frames to
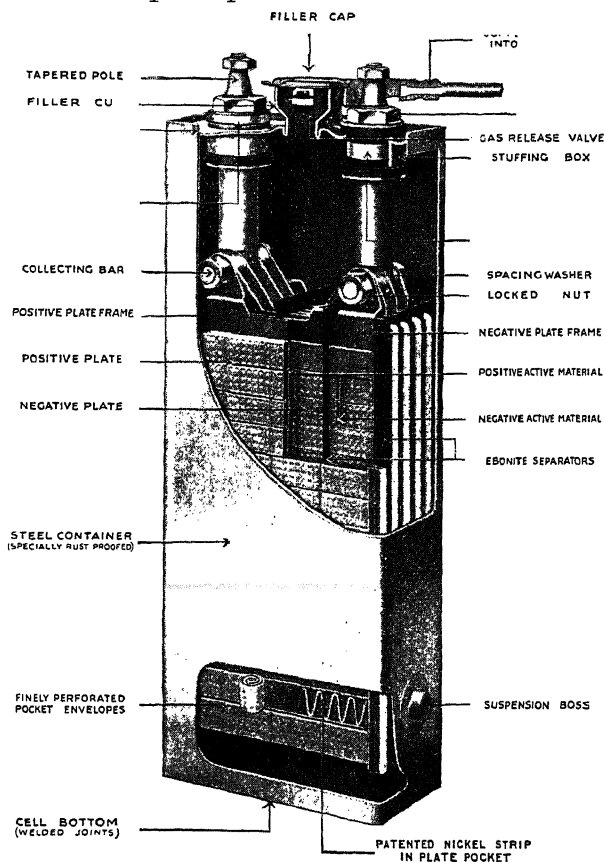form the complete plate. In the Edison nickel-iron

FILLER CAP

TAPERED POLE

FILLER CU

GAS RELEASE VALVE

STUFFING BOX

COLLECTING BAR

SPACING WASHER

LOCKED NUT

POSITIVE PLATE FRAME

NEGATIVE PLATE FRAME

POSITIVE PLATE

POSITIVE ACTIVE MATERIAL

NEGATIVE PLATE

NEGATIVE ACTIVE MATERIAL

EBONITE SEPARATORS

STEEL CONTAINER
(SPECIALLY RUST PROOFED)

FINELY PERFORATED
POCKET ENVELOPES

SUSPENSION BOSS

CELL BOTTOM
(WELDED JOINTS)

PATENTED NICKEL STRIP
IN PLATE POCKET

FIG. 122. C.A.V. NI-FE ALKALINE ACCUMULATOR

cell, the tubes or pockets are arranged vertically,
while in the "Ni-fe" nickel-cadmium cell, shown in

Fig. 122, the pockets are of rectangular cross-section and extend horizontally. The latter, known as the C.A.V.-Ni-fe, is available in this country and the following detailed description will refer to this type.

The positive or negative plates are identical in construction but contain different active material. The necessary number of positive plates is mounted on connecting bars or bolts and spaced apart by washers and by the lugs of the terminal pillars. A similar group of negative plates is assembled and interleaved with a positive set, adjacent plates being separated by ebonite rod insulators. The plate assembly is enclosed in a welded steel container and the terminals are brought through the covers in a liquid and gas tight manner by insulated glands or stuffing boxes. The steel container is frequently plated on the outside to avoid rust.

In both the nickel-iron and the nickel-cadmium cell the active material in the positive plates consists of nickel hydroxide. In the nickel-iron cell the active material in the negative plate is metallic iron, while in the nickel-cadmium cell the iron is replaced by cadmium. In the positive cell during discharge the nickel hydroxide is reduced to a lower form, while in the negative cell the metallic iron or cadmium is oxidized. The plates are immersed in an electrolyte consisting generally of potassium hydroxide solution which must be quite pure, special care being taken that there is no trace of acid.

There is considerable uncertainty regarding the chemical actions which take place, since various oxides of nickel, iron, and cadmium appear to be formed simultaneously and *vice versa*. The electrolyte does not appear in the chemical equations; it seems to function merely as a conductor. This enables a very small quantity to be used so that the plates can be

placed close together, the only limit in this direction being temperature rise.

In accumulators used for engine starting which have to provide a very heavy current, although for periods of only a few seconds, the internal resistance of the
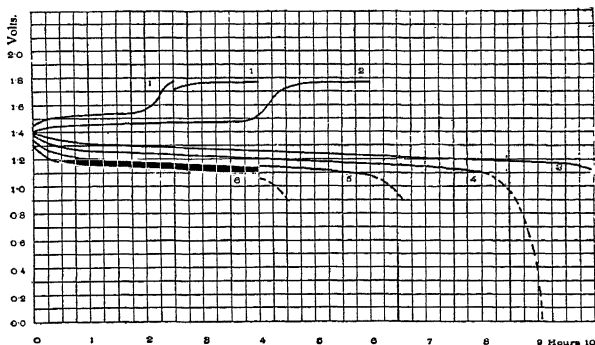

FIG. 123. VOLTAGE AND DISCHARGE PERIODS PER CELL

cell is of the greatest importance, and the high electrical resistance of the active materials employed in alkaline cells has been overcome in several ways. In one method the nickel hydroxide is mixed with small very thin flakes of pure nickel to bring the active material into better electrical contact with the steel pockets or tubes. In another method nickel hydroxide is very carefully mixed with flaked graphite. In the Ni-fe cells the internal resistance has been very greatly reduced by a slight modification of the construction. Inside each pocket is inserted a very thin waved strip of pure nickel ribbon as shown in Fig. 122. This ribbon is just as wide as the inside of the pocket, so that the active material is completely subdivided into a number of small sections. The ribbon extends right into the retaining frames of the plates, and in this

way the active material is brought into much closer electrical contact with the metal.

The alkaline cell is lighter than the lead cell and is able to stand without damage almost any amount of severe treatment and neglect, whereas the lead accumulator is a comparatively delicate piece of apparatus and requires careful treatment. The alkaline accumulator can be charged or discharged at extremely rapid rates; it can be short circuited, completely discharged and left standing indefinitely without permanent injury; further, there is very little leakage when it is left standing, while the plates which consist of steel tubes or pockets do not buckle or deform. The effective voltage of each alkaline cell is, however, only 1·2 volts against the 2 volts of a lead acid cell, so that five alkaline cells as compared with three lead-acid cells are required for a 6 volt accumulator.

The efficiency of the alkaline accumulator is slightly lower than that of the lead accumulator, being between 60 and 65 per cent. The manner in which the voltage of one cell varies under different conditions of charge and discharge is shown in Fig. 123. The two curves 1, 2, show how the voltage varies during what may be described as a forced charge and a normal charge. With the former the charging voltage is slightly higher. When the accumulator is about 17 per cent charged the voltage rises a certain amount but remains substantially constant until the charge is completed.

Whatever the charging rate, the voltage when the accumulator is fully discharged is about 1·1, but during the greater part of the discharge period it remains at 1·2. For long discharge periods at a slow rate the voltage remains slightly higher. The conditions during discharge periods, varying from 10 to 4 hours, are shown by the curves 3 to 6.

ACCESSORIES

THE fitting of electrical accessories has on many modern vehicles made heavy demands on the battery and dynamo, the effect of which is specially noticeable in winter. Electricity is in fact applied in some instances, such as fuel pumps, where non-electrical accessories would function with equal effectiveness. In some cases, electricity is of course essential, as for lamps, while for others it is convenient though not indispensable.

The circuit diagram, Fig. 97, shows the relationship of the accessories to the main electrical components. Certain of the accessories including the direction indicator, fuel level gauge, horn, panel lights, stop lamp, screen-wiper, are put out of operation when the engine is switched off, these parts being supplied from terminals A4 which in turn are supplied from terminal A3—1G on the lighting and ignition switch, only when the ignition is switched on. A description of principles and of the construction of typical accessories is given below.

Lamps. The lamps on motor vehicles fall into two main classes and include the following—

(1) The headlamps, including the pass light, which are intended to project a comparatively narrow beam of light a considerable distance ahead in the path of the vehicle.

(2) The side, tail, stop and reverse lamps, the interior lights, dash or instrument board lamps, direction indicator lamps, 30 m.p.h. warning lamp, all of which are intended to diffuse light widely, so that they may be seen from various directions or may definitely illuminate certain objects.

For safe and reasonably rapid movement at night headlamps are essential, but the problems concerning

their effective use without causing dazzle to other road users call for serious consideration.

Briefly, a headlamp collects light from the source, that is, the incandescent filament, and concentrates it in one general direction, so that the intensity in that direction is very much greater than the intensity of the light at the source itself. This necessitates a reflector and the form of reflector universally adopted is the paraboloid, that is, the surface of revolution formed by the rotation of the section of a cone known as a parabola about its axis.

Before going further into the principles of headlamp projection, consideration will first be given to the physical principles upon which headlamps are based, namely, the laws of reflection and refraction. The direction of any particular ray or pencil of light from any source is changed in a definite manner when it strikes a reflecting surface. This direction is defined by the normal, that is, the line perpendicular to the surface at the point of reflection. The incident ray and the reflected ray both lie in the plane containing the normal and both make the same angle with the normal; that is, the angle of incidence is equal to the angle of reflection. Upon this law depends the fact that the light emitted in all directions from the filament of the headlamp bulb can be controlled and directed so as to form a suitable and intensely brilliant beam. Reflection is thus in direct contrast with diffusion. Surfaces may be divided broadly into reflecting and ordinary diffusing or matt surfaces. Light, however definitely directed, falling upon an ordinary matt surface, is diffused from such surface more or less uniformly in all directions.

When a ray of light passes into or through glass or other transparent medium, its direction changes in accordance with strictly defined laws. Its velocity is

less in the denser medium (glass) than in the rarer medium (air). When the ray is normal to the surface, it suffers no change of direction. But when it travels in a direction which is inclined to the normal, its path in the denser medium lies at a smaller angle to the
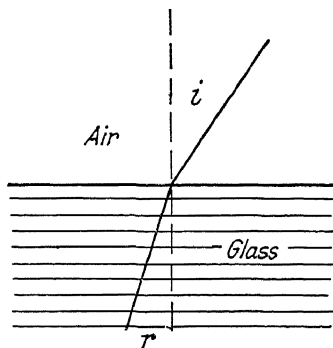

Fig. 124. Refraction

normal than it does in the rarer medium. That is, it bends towards the normal. The converse effect takes place when it leaves the dense medium and emerges into the air. The amount of this refraction varies with the density of the glass.

The coefficient of refraction depends upon the ratio of the angles of incidence and refraction. Referring to Fig. 124 the coefficient of refraction equals—

$$\frac{\text{Sin } i}{\text{Sin } r}$$

The coefficient of refraction varies considerably according to the density of the glass, but for the glass used for headlamp and other front glasses, its value is very close to 1·5. The deflection of the different colours of which the spectrum of white light is composed varies slightly in any given specimen of glass, but this

dispersing or chromatic effect by which in certain circumstances various colours are obtained, need not be considered in connection with lamps.

The light which is emitted from the incandescent filament of the bulb is by no means all utilized in the beam. There is considerable wastage both at the surface of the reflector and in transmission through glass. The reflecting surface in headlamps is with few exceptions silver-plated and polished, since such a surface wastes a smaller proportion of the light falling on it than nearly any other metal or glass surface.

A silver surface reflects from 87 to 95 per cent of the visible rays, the proportion of long rays being slightly higher than that of short rays, that is, more light from the red end than from the blue end of the spectrum is reflected.

Silver, in common with most polished metallic surfaces, reflects nearly the whole of the infra-red rays and only about one-third of the ultra-violet rays. Polished steel reflects about 55 per cent, platinum 61 per cent, and nickel about 63 per cent of the visible rays, so that these metals are definitely inferior to silver in this respect. The alloy known as "magnalium," containing 69 per cent of aluminium, and 31 per cent of magnesium, reflects about 83 per cent of the visible rays.

The figures mentioned apply to reflectors in good condition. There is a rapid falling off when the surface dims or becomes scratched through unwise and unnecessary cleaning. The silver reflector is often protected from damage without serious loss of light by a very fine coating of transparent varnish.

When light is transmitted through glass, a certain loss occurs at every surface. In the case of optical glass, which is very clear and carefully polished, the loss is approximately 5 per cent at every surface, so

that light passing from one side to the other of a lens through two surfaces loses approximately 10 per cent. The glasses used in motor-car lamps are generally not of this quality, and the loss is greater.

The loss of light by reflection on a glass mirror is also serious, since losses occur both when the light enters and leaves the outer surface of the mirror, and also when it is reflected from the back. A mirror consisting of glass silvered at the back by a mercury compound reflects finally little more than 75 per cent of the light falling upon it. Silvered glass is thus distinctly inferior to a metallic silver mirror.

The source of light, that is, the point where a certain fraction of the electrical energy available is converted into light, is always an incandescent filament of special shape, which works under somewhat exacting conditions, since it is often subjected to vibration and may be supplied with voltage varying by 10 per cent or more from that on which it is intended to run. For instance, a freshly charged battery may for a short time deliver current substantially above the rated voltage.

Bulb filaments could in fact be designed to run at a higher temperature, and at a higher efficiency but for the necessity of leaving a margin of safety to deal with occasional excess voltages. The amount of light obtainable from a filament supplied with a given quantity of electrical energy depends upon the temperature at which the filament can be run without melting it, or reducing its useful life. One thousand hours is often mentioned as the useful life of the filament of a lamp, but this may be substantially reduced if the lamp is run at a higher voltage than that for which it is designed, apart from the greater risk of accidental damage.

The filament is commonly made of a short length of

fine tungsten wire, mounted on electrodes of larger section and enclosed in a sealed glass bulb. When such a filament is raised to incandescence, it will burn very rapidly in the presence of oxygen. To avoid this, at one time, the bulb was exhausted by a vacuum pump, and the temperature to which the filament could be raised, then resulted in a somewhat yellowish light. Nearly all motor-car bulbs to-day are, however, of the gas-filled type, in which a certain quantity of an inert gas such as nitrogen is introduced into the bulb, and helps to regulate the temperature of the filament, since convection currents bring about continual circulation, and the gas carries away heat from the filament at a uniform rate. The filament may therefore be raised to a higher temperature than it could be in a vacuum bulb. The light is whiter and more intense, and higher candle-power is obtainable for a given consumption of energy.

Associated with this development, was a modification in the shape of the filament, which was coiled closely in the form of a helix, the wire also being of rather heavier gauge for a given size of lamp. In this way, shorter filaments became available, thus forming a more concentrated source of light, the advantages of which will be dealt with later.

Some recent developments include the coiled coil filament in which the wire is first wound so as to form a fine helix, which is again wound so as to form a larger helix. Only by the continual circulation of the inert gas round and through the very close coils of the helices is it possible to maintain a high degree of incandescence, without serious risk of fusion of the wire.

Some examples of filament shapes supplied by Joseph Lucas, Ltd., are shown in Fig. 125. These include—

(a) V filaments used largely with headlamps having specially shaped front glasses, the filaments being

arranged horizontally with the apex of the V towards the front of the lamp.

(b) Axial filaments lying along the axis of the lamp intended for use with clear or diffusing glass.

(c) Transverse filaments.

(d) Curved or standard side lamp filaments, as used also for tail, dash and roof lamps, etc.

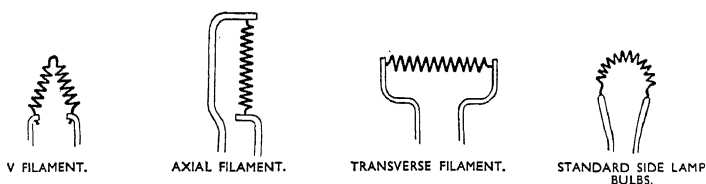The first three of the above filaments are intended

V FILAMENT. AXIAL FILAMENT. TRANSVERSE FILAMENT. STANDARD SIDE LAMP BULBS.

FIG. 125. LAMP FILAMENTS

for headlamps and pass lamps. Other forms of filament as used for non-dazzle purposes will be referred to later.

The diameter of the filament wire and the length are carefully designed to have a certain resistance, so that when the required voltage is applied, the filament will be raised to the desired incandescent temperature. Filaments are necessarily very sensitive to voltage, since a slight excess results in such a rise of temperature that the light intensity increases as the fourth power of the voltage.

It is well to consider exactly what the headlamps are expected to do, from the driver's point of view. Broadly non-reflecting objects are seen by means of light which is directed on to them, and is diffused in all directions, thereby producing contrasts by which outlines and differences of colour and tone can be distinguished. Perfect reflecting objects cannot be seen since the light which strikes them is reflected in a definite direction

only. It may form one or more virtual images of the source, but it does not enable the form of such an object to be seen by the driver or other observer. Imperfect reflecting surfaces, such as wet roads, which combine these two effects of reflection and diffusion, are very confusing to the driver.

The headlamp projects a beam of light forward, and this light as it strikes a non-reflecting or matt object is diffused in all directions, and the object is thus visible from all points of view, including that of the driver. Colour by itself does not appear to be of much consequence at night, but the shade or tone, that is the lightness or darkess of the surface, is of importance. Tone values can to some extent be compared independently of colour, and the contrast at night between light and dark objects is very great. It is probably correct to say that the driver of a car sees almost entirely by contrasting tones which form silhouettes against one another. The difficulty of seeing the wearer of a dark coat is greater on a background formed by the surface of a black road, than it would be on a light coloured road. Movement of the object across the line of sight also facilitates vision. The capacity of a driver for seeing objects by means of his headlamps thus depends upon the intensity of the light, which actually strikes the object, the character of the surface of the object, and the contrast with the background or with other objects.

When driving along a straight road, it is necessary for clear vision that the part of the beam which projects straight along the road should be much more intense than that which is directed towards the sides of the road. A very steep gradation of intensity sideways is thus possible, and is in fact essential if the maximum useful result is to be obtained from the limited amount of light available at the source.

Most modern motor-car headlamps are designed to spread the light sideways rather than upwards, so as to cover the full width of the road some distance ahead with a beam of maximum strength, the sides of the road being illuminated satisfactorily by rays of much lower intensity.

The headlamp reflector utilizes a well-known property of the parabola—that the normal at any point on the curve bisects the line running from this point to the focus and a line parallel with the axis. As a consequence, a point source of light at the focus directs rays or pencils of light from all points on the surface of a paraboloid in directions parallel with the axis. This principle is shown in Fig. 126. If such a point source were available, the beam would not diverge or spread, but would remain parallel with the axis, and would be
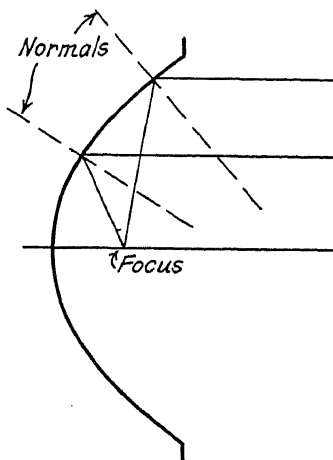
FIG. 126. THE PARABOLA

of uniform cross-section (equal to the circular front of the reflector). It would also remain of uniform intensity. This is of course a mathematical conception impossible of realization, since the fact that the source of light must have finite dimensions results in a spreading of the light, so that the beam diverges and the average intensity over a cross-section correspondingly diminishes as the distance from the lamp increases. Fig. 127 shows diagrammatically several of the small divergent beams due to reflection at certain points, the source

being assumed to be a small sphere, the centre of which coincides with the focus of the paraboloid.

The rays from the focus are reflected in directions parallel with the axis, but the rays passing to the same point on the reflector from the sides of the spherical source are reflected on each side of the main ray. Thus the ray emanating from a point behind the focus is reflected in a direction diverging from the axis, while conversely a ray emanating from a point in front of the
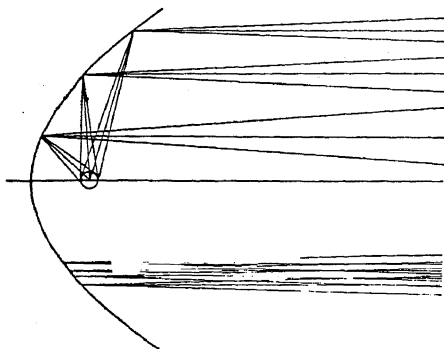
FIG. 127. PARABOLIC REFLECTOR
(By courtesy of the Illuminating Engineering Society.)

focus is reflected so as to converge towards the axis. The angle of spread is greater for points on the reflector near the focus than for those more remote. The converging rays ultimately cross the axis of the lamp, and then diverge so that all the rays continue to form a diverging beam. This property of the parabola will be dealt with later in connection with filament shapes and the prevention of dazzle.

Reference has already been made to losses of light due to imperfections in reflecting surfaces, and to losses in passing through the front glass. An even more serious source of loss is due to the fact that only a certain proportion of the total light emitted in all

directions from the filament can be intercepted by the reflector and directed forwardly. This is shown in Fig. 128 in which the source of light is at a focus common to both the large and the small parabolic reflectors shown in outline. The light from such a point source is emitted uniformly in all directions. It is regarded for present purposes as divided up into zones of a sphere. All the light from the back half of this hemisphere, that is, 50 per cent of the whole, is intercepted by the reflector, and projected forward with the exception of a small quantity, the reflection of which is interrupted by the bulbholder and the glass of the bulb.

Imagine the light from the right-hand side of the sphere to be divided up into a series of cones having
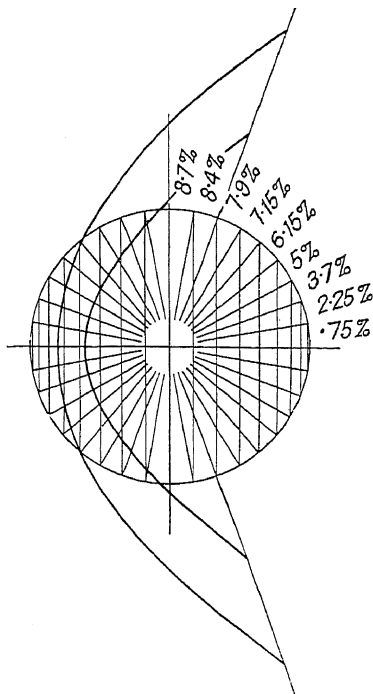
FIG. 128. PARABOLIC REFLECTORS
(By courtesy of the Illuminating Engineering Society.)

semi-vertical angles of 10°, 20°, 30°, etc., and having a common axis, namely, the axis of the bulb and lamp. The first cone emits only 0·75 per cent of the total spherical candle power, the second cone increases this by 2·25 per cent, the third cone by 3·7 per cent, and so on. But none of these cones or zones of light are

intercepted by the reflector except the last two, namely, the two supplying 8·7 per cent and 8·4 per cent. The maximum amount of light which can be reflected forward to form the beam is thus about 65 per cent. The remaining 35 per cent directs a wide-angled cone of light straight from the source; the intensity being very small, and of little practical value.

It will thus be seen how small a proportion of the total light available from the source can be projected into the beam and also how little this proportion is affected by the diameter of the reflector, so that large headlamps may be regarded as fitted more for ornament than use. The smaller headlamps will, for a given filament, project a beam which is slightly more divergent and therefore slightly less intense than the larger headlamps; but this is not of much importance since, in order to obtain a satisfactory driving light, it is necessary to modify the front glass so as to diffuse the light. The beam of light projected through a plain glass is too irregular and streaky to give a satisfactory driving light. Moreover, it is for practical purposes too narrow, and in order to obtain width the intensity can be reduced and still leave adequate penetration.

One way of considering the effectiveness of headlamps is to compare the candle-power in the beam with the candle-power emitted from the source. It is possible, employing very faintly ground glass, sufficient only to avoid excessive striations, to obtain a candle-power in the beam 900 times that emitted from the source. This however is excessive and, moreover, the beam is too narrow to cover adequately the full width of the road, and a better result is obtained by stronger diffusing glasses, preferably prismatic glasses, diffusing the light laterally to such an extent that the intensity at the source is multiplied about 300 times.

There is thus a considerable margin for modification

of the beam by special shapes of front glasses, to give greater uniformity or lateral spread. Uniformity is obtained either by a simple diffusing glass which spreads the beam uniformly in all directions or by vertical flutings or prisms which spread the beam laterally only. The direction and the form of the beam is moreover sensitive to very small differences in the shape and position of the filament, and a variety of different effects is thus obtainable. One such effect, greatly desired in connection with the so-called pass light or fog light is the flat-topped beam, in which an attempt is made to direct all the light on to the ground below the eye-level of other road users. The pass light is in effect a small additional headlamp directed downwardly and often also to one side of the road. It is particularly useful in fog.

Some of the principles underlying the obtaining of these non-dazzle effects in headlamps or more particularly in pass lamps will now be considered. It has previously been made clear that the placing of the filament in front of the focus of the paraboloid results in a converging beam which crosses the axis and then diverges, whereas a filament located behind the focus results in a diverging beam. These properties of the paraboloid are utilized in several ways. In Fig. 129 is shown a filament preferably of V shape with the V lying in a horizontal plane, arranged behind the focus F. The light from the lower half of the reflector forms a flat-topped beam of semicircular cross-section since it all diverges downwardly below the axis of the lamp. The light from the top half of the beam forms similarly an inverted semicircle. To eliminate this upper light, it is only necessary to intercept the upward rays from the filament. This may be effected by obscuring the upper half of the front glass as indicated by A, or by arranging a small metal hemisphere over the top of

the bulb. Half the light is in either case wasted, and attempts have been made to make up some of this loss by silvering the back of the obturator A, or the inside of the hemisphere. Such methods may distribute
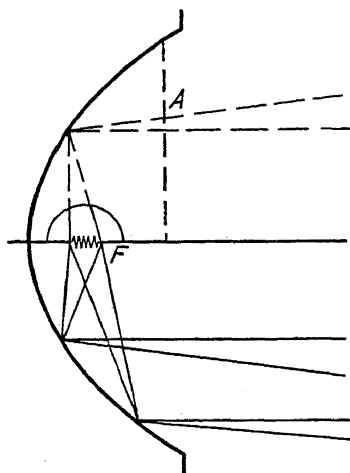
129. Diverging Beam
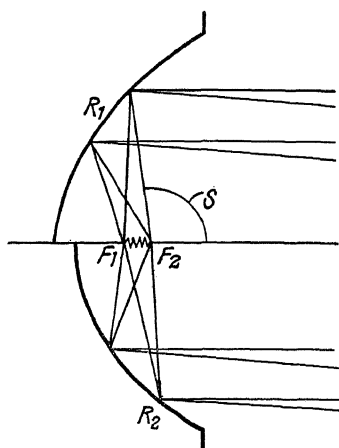
Fig. 130. Two-part
Reflector

excessive heat, but they have a negligible effect in recovering any of the light for use in the beam, since the losses and the diffusion by repeated reflections and re-transmission through the glass of the bulb are very great. The direct upward rays from the filament are also cut out.

The light from both the lower and the upper half of the reflector may, however, be utilized in a flat-topped or downwardly directed beam, by making the reflector in two parts, as shown in Fig. 130, the upper and lower halves of the reflectors $R1$, $R2$ having the foci $F1$, and $F2$ respectively. A filament located

between these foci produces in both cases a downwardly directed beam, and, if the design is correct, the upper and lower semicircles will be superimposed on one another. An additional refinement is a shield S
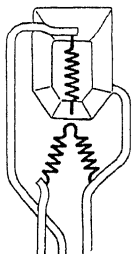
FIG. 131. LUCAS-GRAVES
BI-FOCAL FILAMENTS
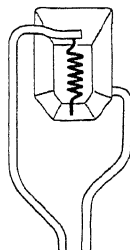
FIG. 132. LUCAS-GRAVES
HOODED FILAMENT

which intercepts the upward direct rays from the filament.

The Lucas-Graves double filament bulb shown in Fig. 131 may be used in an ordinary headlamp to give the usual main driving light, or alternatively a flat-topped beam. The main V-shaped filament is arranged horizontally and as nearly as possible at the focus of the reflector, and when current is supplied to it an ordinary beam modified by the front glass is directed forwardly. When, however, only the axial filament is supplied with current, a converging beam is produced since this filament is located in front of the focus. A shield underneath the filament cuts off the downward rays so that only a dipped beam from the upper half of the reflector is projected ahead.

The Lucas-Graves hooded filament shown in Fig. 132 is arranged in front of the focus of the lamp to give a flat-topped beam in fog, etc.

Another form of Lucas bi-focal bulb is shown in Fig. 133. The main V filament is arranged in the focus, and

functions in the usual way. Two forms are available. In one the additional filament is arranged as shown on the right of the figure, so that when it alone is energized the beam dips vertically downwards. As an alternative, the auxiliary filament may be arranged to one side at say 10.30 o'clock so that the auxiliary beam dips to the near side.
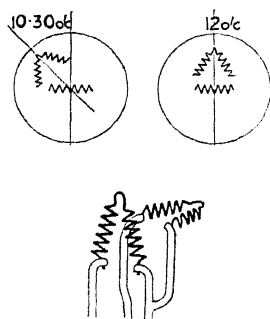
Fig. 133.   Lucas Dipping Beam Bi-focal

The headlamp is clearly very sensitive to the exact positioning of the filament in relation to the focus. Headlamp bulbs are now manufactured with such accuracy that the filament lies on the axis of the cylindrical stem, so that it is always accurately located on the axis of the reflector, and there is no need for any adjustment other than that in the direction of the axis. In some cases, the distance between the filament and the bayonet pins is also standardized so that no focusing is necessary, provided the correct bulb is used. This elimination of the human element is a great aid to accuracy in projection.

A headlamp must obviously be mounted on a car in a perfectly rigid manner and preferably so that damage to the mudguard cannot deflect the beam. This is essential for two reasons, firstly, quite a small variation in the angle of the lamp due to a very small amount of shaking will result in considerable deflection of the beam, for the amount of any movement is magnified by the beam many hundred times, and such deflections may seriously affect the comfort and safety of the driver. Secondly the effect of vibration on the delicate filaments of the bulb may cause breakage.

Such vibrations are due not only to ordinary road shocks and to engine vibration, but to high frequency vibrations due to an electric horn. In modern vehicles, the engine units are commonly so mounted that their vibrations do not affect the frame, while good springing and large low-pressure tyres reduce the road shocks to a minimum, but in commercial vehicles, particularly those with compression-ignition engines, the question of engine vibration and road shocks is much more serious. Flexible mounting of the horn will tend to prevent transference of high frequency vibrations to the lamp filaments.

In the wiring diagram, Fig. 97, a well-known arrangement of two headlamps is illustrated in which the near-side headlamp is provided with a reflector which dips downwards and to the near side when required, the right-hand headlamp being simultaneously extinguished.

A Lucas dipping reflector with the internal operating mechanism visible is shown in Fig. 134. The reflector is pivoted on the front of the lamp, the pivots lying at the required angle to the horizontal to ensure the necessary lateral movement when dipping. The reflector carries the bulb in the correct position so that the bulb and the reflector move together. When the dipping switch is closed, current flows through the windings of the dipping reflector unit, the core of which then moves and tilts the reflector against the resistance of its retaining springs. This operation also cuts out the other headlamp and further introduces a resistance into the dipping circuit, so that only sufficient current flows to maintain the reflector dipped, this current being substantially less than that needed for operation.

Other bulbs are used on the car for various purposes. The sidelamps are intended to direct their beams over

SPARE FUSE

SCREW SECURING PROJECTOR FRONT

FUSE

DIPPING REFLECTOR UNIT

JUNCTION BOX

BULB HOLDER REMOVED FROM REFLECTOR
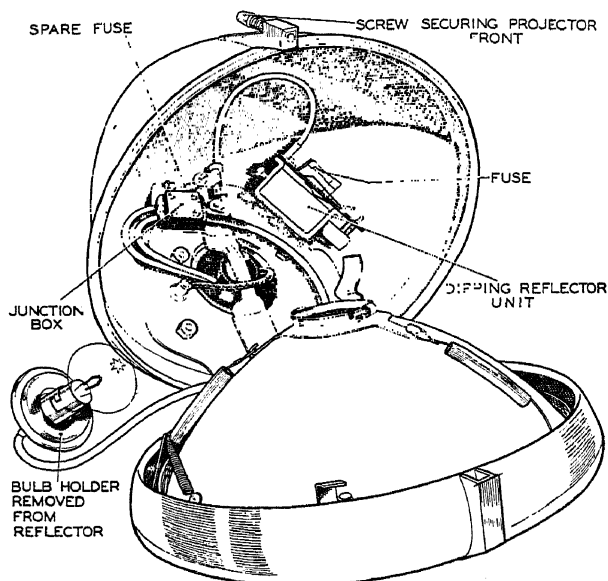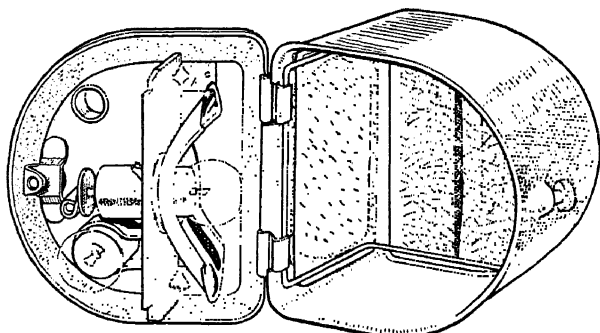
FIG. 134. LUCAS DIPPING REFLECTOR HEADLAMP

FIG. 135. LUCAS COMBINED TAIL AND WARNING LAMP

a very wide area, but the intensity must be kept low to avoid dazzling other road users. They are only intended to indicate the outlines of the car. Accurate parabolic reflectors are thus entirely out of place in side lamps and the light should be diffused laterally by vertical flutings in the front glasses. The same considerations apply to the tail lamp which in addition to showing
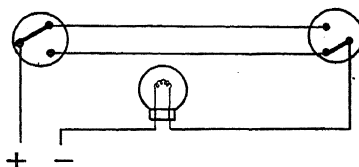
FIG. 136. TWO-SWITCH OPERATION

a red light to the rear, must illuminate the number plate properly. In many cars to-day the tail lamp and the brake-warning lamp are combined in one casing; an example of this construction made by Joseph Lucas, Ltd., is shown in Fig. 135, the two compartments being separated by a diaphragm.

The reverse light, tail lamp and brake-warning lamp may be combined in one casing.

Bulbs of the ordinary side lamp pattern, or the festoon type, are often used for the interior lighting of a vehicle, and in certain cases, provision is made for operating one or more of the interior lamps from two positions, or for operating them automatically when the doors are opened, as well as manually. The former arrangement is shown in Fig. 136 in which the two switches are connected by two leads. Each switch can be turned only to one or the other position, and either switch may thus be operated independently of the other to open or close the circuit through the bulb.

The door operating arrangement is shown in Fig. 137.

The switches associated with the two doors are connected by two independent leads, and each door when closed opens its switch. The circuit through the lamp can then be opened or closed by the manual switch. When either door is opened, its switch is closed and the
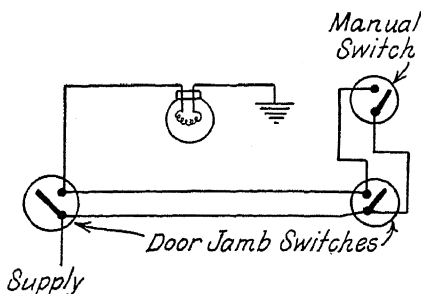
FIG. 137. DOOR OPERATION OF INTERIOR LIGHT

circuit through the lamp completed independently of the manual switch.

Ammeter. The chief electrical indicating instrument on the dashboard is the ammeter, since it gives a guide to the essential matter of the state of charge or discharge of the battery. As mentioned elsewhere, indications given by the ammeter require interpreting in different ways according to whether the car is fitted with third-brush control, or with the more recent constant-voltage control. Ammeters which have previously given satisfaction in connection with third-brush control are liable to get into a state of oscillation when used on C.V.C., since the latter is of an intermittent or rapidly pulsating character. It has therefore been found necessary to modify the design of the ammeter so as to provide damping means.

A diagrammatic view of such an ammeter is shown in Fig. 138. The current passing in either direction

through the ammeter traverses a winding of an electromagnet which acts upon a pivoted soft iron armature to which the pointer is attached, so as to tilt it in one direction or the other on either side of a central position, to indicate the amount of the charge or discharge. A
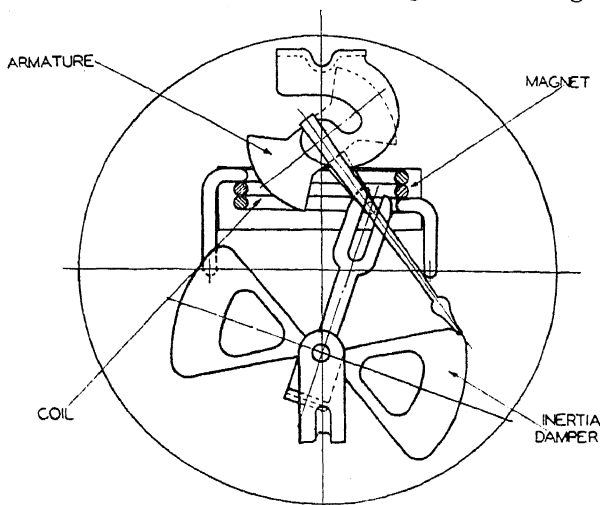
Fig. 138. Ammeter with Inertia and Friction Damping
(By courtesy of the Institution of Automobile Engineers.)

permanent magnet opposes deviations from the central position, but a spring or gravity may be utilized. To prevent oscillations of the indicating arm, combined inertia and friction damping is provided. This consists of a pivoted weight having a pin and slot connection with an extension from the armature. The inertia mass is balanced so that it does not have any effect upon the armature except to retard rapid movements. The friction due to forces acting between the pin and the slot depends upon speed of movement. When the armature is moving slowly, little force is exerted and

the damping effect is small, but if the armature tends to vibrate, larger forces are exerted on the heavy inertia damper, and produce corresponding high frictional forces which exert a substantial damping effect.

Direction Indicators. After various attempts to introduce illuminated direction indicators, the type which has survived is the semaphore in which a movable arm is combined with a light. These are arranged at a distance of 4 or 5 ft. above the ground where they are clearly visible, and it is obviously an accessory in which the use of electricity is essential both for illuminating purposes and for rapid operation. Self-contained units were used originally and were attached to the outside of the front pillar, but the later types which are let into the bodywork have many advantages.

The front pillar on modern cars is made as small as possible to improve visibility, and consequently is too small to contain the semaphore, and its operating mechanism, which is therefore frequently arranged on the middle body pillar or more towards the rear of the car. The disadvantage of this position is the fact that the driver cannot see the arm when it is extended and therefore timing or other means must be adopted to ensure that it does not remain up for longer than is necessary.

The bulb in the arm is usually arranged in parallel with the operating solenoid, both being switched on at the same time, although in some constructions, the bulb is not switched on until the arm has been elevated. A sectional view of an arm and its operating mechanism as made by Joseph Lucas, Ltd., is shown in Fig. 139 in the inoperative position.

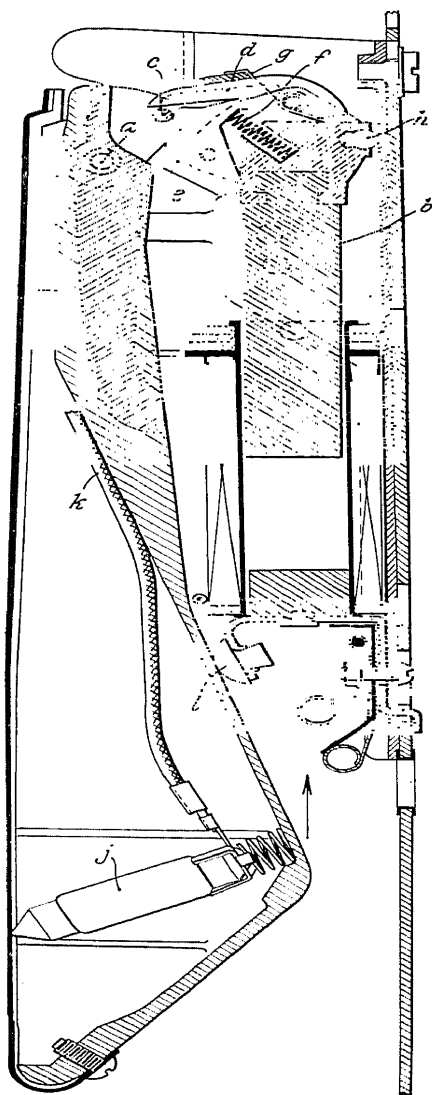The arm is pivoted at a to a framework which is secured to a back plate on the inside of the bodywork,

FIG. 139. LUCAS DIRECTION INDICATOR

the whole assembly being put into position from the interior of the car, so that the only opening on the outside is that needed to accommodate the arm. The arm is raised by downward movement of the iron core b by a solenoid winding, and the upper end of the arm carries mechanism adapted to move the arm up and down and lock it in its raised or lowered positions, preferably in a yielding manner, such that although locked the arm will yield if force is applied to it.

When the solenoid core is moved downwards by energization of its winding, the small arm d at its upper end engages a pin c on the main arm, whereby it is raised. During this raising movement the pin c slides to the right and is held in a yielding manner between the arm d and the shaped upper face of a lever e pivoted to the core. The lever e is forced upwards by a coiled spring f and the lever d is urged downwards by a plate spring g. When the current is switched off, the weight of the arm moves it downwards, the pin c then overcoming the spring resistance of levers d and e until it engages the vertical outer face of the lever e when spring f locks it in its inoperative position.

A ball h reduces friction between the solenoid and the casing. The festoon type bulb j in the arm is supplied through a light flexible lead k. A rubber buffer l prevents shock when the arm falls.

The current required for the operation of the solenoid and the bulb is small, and, apart from this, the indicators are used for very short periods.

As mentioned above, it is essential with indicators which are not clearly visible to the driver, that some warning or cancelling device should be employed. This may consist of a coloured flashlamp bulb with series resistance across the leads to the signal arms as shown in Fig. 140. When the changeover switch is turned in either direction to operate the appropriate signal, some

current also flows to the other signal through the flash-lamp, this current being sufficient to illuminate the flashlamp, but insufficient to operate the arm, or to illuminate its bulb.

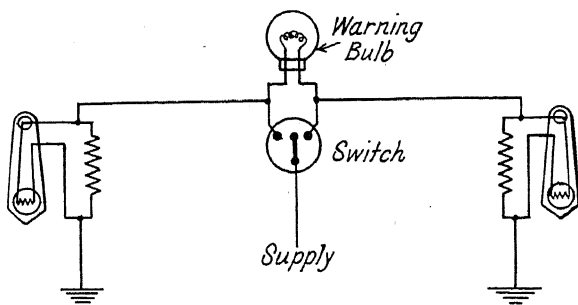The cancelling devices may be of the time type, or of the type in which the movement of the steering

FIG. 140. DIRECTION INDICATOR WARNING LIGHT

wheel in the intended direction de-energizes the signal which has been operated. In the former type clock-work mechanism, started when the signal is operated, may be used to open the circuit after the necessary interval of time, for example, eight or ten seconds. Alternatively, a bi-metallic heating strip may open the circuit or return the switch to the neutral position after a suitable interval.

In the second type, the mechanism is somewhat more complicated since it has to be carefully correlated with the steering gear and even then the movement of the steering wheels may be insufficient to ensure cancellation in every case. Hand operation in addition to the automatic operation is always necessary.

Horns. The provision of electric horns entirely suited to modern traffic conditions is very difficult. The tone must be sufficiently penetrating to attract

attention, but should not be of a nerve-shattering character.

Horns may be broadly classified according to the kind of sound produced and this depends upon whether they are or are not fitted with an orchestral-like trumpet forming the outlet for the sound. In one case the sound is simply a raucous noise, while in the other case it may be of a more musical character, not essentially displeasing and yet sufficiently penetrating.

A little consideration of the nature of sound is desirable. The transmission of sound, unlike light, depends very much upon the medium. Sound vibrations may be transmitted through liquids, but consideration will here only be given to transmission through air.

Sound is essentially a particular kind of rhythmic movement transmitted to and through the air. In all horns, the sound is initiated by small rapid in and out movements of a flexible diaphragm, these movements causing alternate waves of compression and rarefaction of the air. The waves are transmitted in all directions, and although there may be certain variations in the intensity in certain directions these variations are not very great. The velocity of sound is 1100 ft. per second.

The comparatively pleasing character of the sound emitted by the old bulb horns was due to the fact that the vibrating diaphragm was located at the inner end of a fairly long flared inlet, and that the reed initiated a series of natural pulsations, the pitch of which depended upon the horn. Such horns were, however, not sufficiently penetrating under all conditions and were superseded by those of the buzzer type, in which the diaphragm imparted to the air what might be described as a series of rapid independent noises not associated with one another and without the mathematical relationship necessary to constitute a sound. Such impulses were imparted to the diaphragm by

mechanical or electrical means. In one type an electric motor, which started when the horn button was pressed, rotated a serrated ring which imparted a series of blows to a hard steel button fixed to the centre of the diaphragm.

This type of horn was in turn replaced by the high-frequency or impact type in which the core of a solenoid
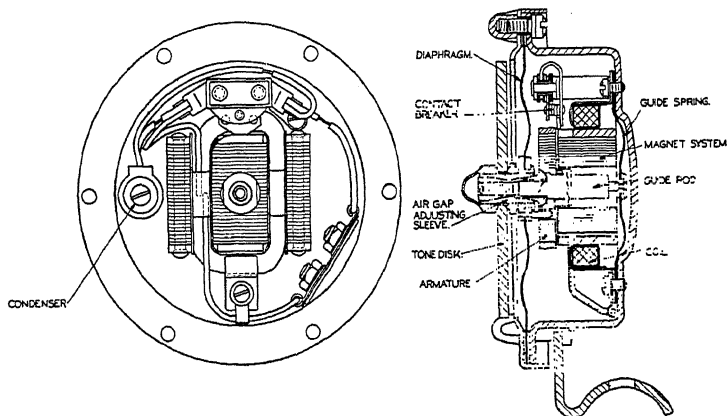

FIG. 141. HIGH-FREQUENCY HORN
(By courtesy of the Institution of Automobile Engineers.)

rapidly reciprocated by means of a contact-breaker, imparts a series of blows to the diaphragm. In this case, the important factor is not the frequency of the impulses directly impacted by the moving element to the horn, but the overtones or harmonics, set up in the diaphragm or the tone disc itself. The quality of the note or combination of notes emitted, depends very much upon the detailed design and careful tuning of the diaphragm.

Two views of a typical high-frequency horn are shown in Fig. 141.

An electrical horn having a trumpet-like note and

known as the Mellotone is shown in Fig. 141A, this horn being made by Joseph Lucas. The diaphragm is oscillated by an electro-magnet and contact-breaker associated with a condenser, the working parts being protected by a dome-like cover. The chamber on the
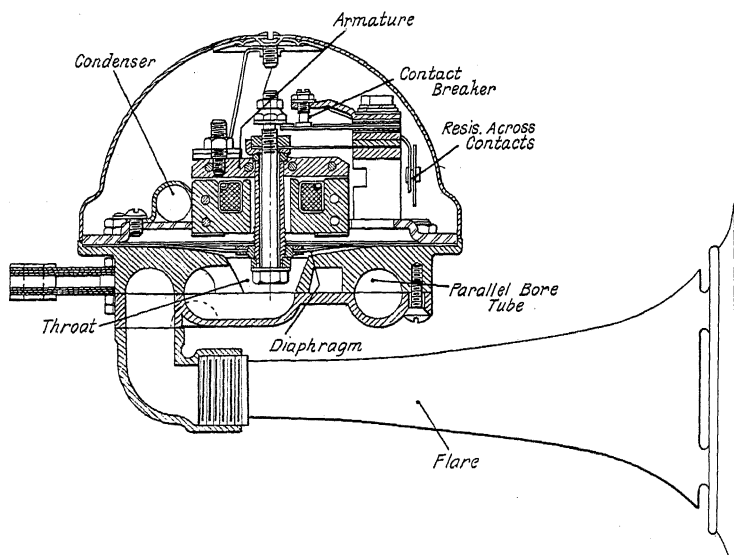
FIG. 141A. LUCAS MELLOTONE HORN

lower side of the diaphragm opens into a tube which follows a horizontal spiral path leading to the atmosphere through the horn proper or flared open end. The sound thus depends upon the resonance of an air column in the long passage from the diaphragm to the final outlet.

These horns are intended to be used in pairs, one having a longer air column than the other, so as to provide a different note. Both horns are then controlled

simultaneously by a push button which can be worked in one direction or the other, so that either soft tones or loud tones are provided according to requirements. To produce the soft tones a series resistance reduces the voltage applied across the contact-breaker.

Fuel and Oil Gauges. The general use of rear tanks on cars makes some form of remotely operated fuel level gauge essential, and electrical operation is employed at the present time with very few exceptions. Very little current is used, and it possesses distinct advantages over any other type of indicator. The essential components include an indicating instrument or meter resembling an ammeter on the dashboard, and a transmitting element secured to the tank and operated by a float.

The two components of a simple typical system are shown in Fig. 142. The float actuates directly a contact arm which moves over a wound wire rheostat or variable resistance and short circuits a number of the windings depending upon the level of the fuel. The deflecting coil of the meter influences an unwound pivoted element carrying the pointer.

The obvious method of returning the pointer to zero is a weight or spring acting in opposition to the control coil, but in this case the reading would obviously depend not only on the fuel level, but on the voltage of the battery, and would render the gauge unreliable. The meter is therefore always provided, in addition to the deflecting coil, with a control coil which returns the pointer to zero and takes the place of the spring or gravity return of an ammeter.

Various methods of connecting the meter coils and the rheostat of the transmitter may be used.

In the constant control type shown in the wiring diagram Fig. 143, closure of the ignition switch completes two parallel circuits, one through the control

coil to earth and the other through the deflecting coil and the rheostat in the transmitter to earth.   Any
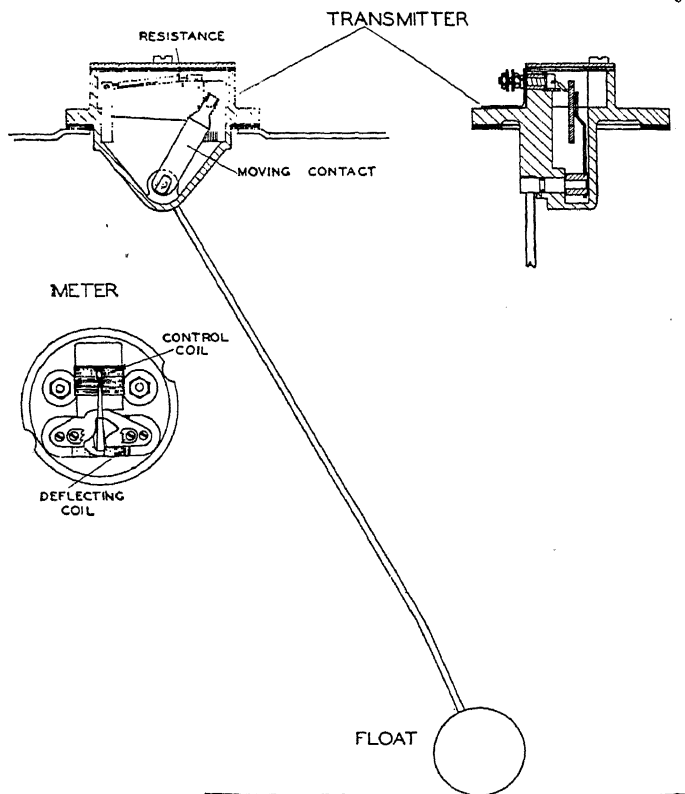

FIG. 142. PETROL GAUGE
(By courtesy of the Institution of Automobile Engineers.)

variations of voltage influence both coils in the same direction so that the indications of the meter are not affected thereby.

The system may be modified to form a variable control system by connecting the contact coil to the other

terminal of the meter so that all the supply current
passes first through the deflecting coil after which it is
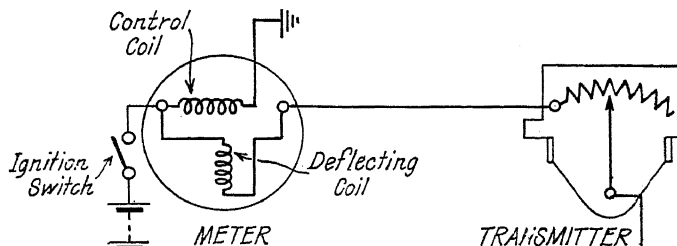
FIG. 143. PETROL GAUGE CONNECTIONS AND CONSTANT
CONTROL

led to earth through the control coil and the rheostat
arranged in parallel.

A diagram of a variable control system supplied by
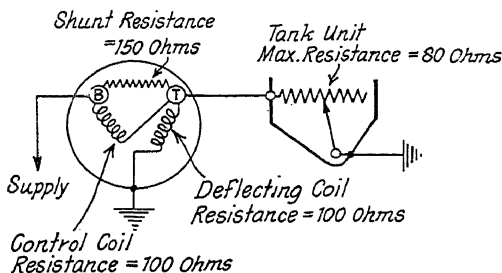
FIG. 144. S. SMITH & SONS' VARIABLE CONTROL SYSTEM

S. Smith & Sons (Motor Accessories) Ltd. is shown in
Fig. 144, various resistance data for a 12-volt meter
being included on the diagram. In this case, the excita-
tion of both the deflecting coil and the control coil
varies. The supply current passes from terminal B
through the control coil and the shunt resistance to
terminal T, from which it is led to earth through the

parallel-connected deflecting coil and the rheostat in the tank unit.

No attempt is made to exclude petrol or petrol vapour from the interior of such instruments where sparking might occur due to bad contact in the rheostat or its connections. The only communication between the two is through the very small clearance space between the operating spindle, and its bearing and tests have failed to show that flame can be transmitted from the interior of the instrument to the tank. The suggestion has been made that the fine clearance of the spindle acts like the gauze of a safety lamp. Risk of fire from this cause is thus negligible.

It is obvious that similar mechanism may be used to inform the driver as to the level of the oil in the sump of the engine. In the wiring system of Fig. 97 a switch is provided by means of which a transmitting element operated by a float in the sump is connected to the meter on the dashboard, in place of the transmitting element in the petrol tank.

Electric Fuel Pumps. The general use of rear tanks, due to the reduced risk of fire as compared with dashboard tanks, makes necessary the provision of some form of fuel lift, since, in most motor vehicles, the fuel tank is at a lower level than the carburettor, particularly when the vehicle is running uphill. Fuel pumps of either the mechanical or electrical type have superseded the vacuum apparatus once generally used for this purpose. In both types a chamber of continually varying capacity is connected through one-way valves to the petrol tank and to the float chamber of the carburettor, the rate of operation of the pump being dependent upon the demands of the engine transmitted through the float chamber. The chamber of varying capacity may be formed by a piston working in a cylinder or by a flexible diaphragm forming one wall of the

chamber. The diaphragm construction is generally preferable, since it avoids the possibility of leakage. The piston or the diaphragm is operated either mechanically by the engine or electrically.

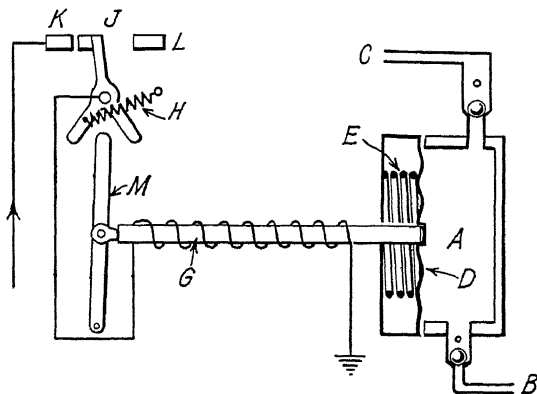The principle of electric operation in connection with a diaphragm pump is illustrated in Fig. 145. To the

FIG. 145. PRINCIPLE OF ELECTRIC FUEL PUMP

chamber A is connected through one way valves, the suction pipe B from the tank and the delivery pipe C to the float chamber. The flexible diaphragm D closes one side of chamber A and is forced inward by a spring E and drawn outward by the armature G of a solenoid, the circuit of which is opened and closed by throw-over mechanism operating the contact points, the throw-over mechanism, shown diagrammatically, consisting of a three-armed lever controlled by a spring H in such a way that the movable contact J is held firmly either against the fixed contact K connected to the ignition switch or against a stop L, the lever being tilted either way by a lever M connected to the armature G. At each end of its travel, the armature

throws over the movable contact whereby its direction of movement is reversed.

The widely used electric pressure pump made by the S.U. Carburettor Co. Ltd. is shown in Fig. 146, this instrument being capable of delivering 8 gallons of petrol per hour against a suction lift of 4 ft. It should be located slightly above and as close to the carburettor as possible.

The pump consists of three main components—the body, the actuating electro-magnet, and the automatic contact-breaker. The inlet C and the outlet D are arranged at the top of the body A with the filter B at the bottom. The inlet or suction valve K and the delivery valve H consist of thin brass discs, the latter being held in position by a spring clip. The space between the valves is connected to the pumping chamber which consists of a shallow depression on the forward face of the body, this space being closed by a diaphragm L clamped between the magnet housing M and the body A.

The operating electro-magnet is energized intermittently through the contact-breaker, and the movement of the armature in opposition to a spring imparts pulsations to the diaphragm. The armature is located centrally within the magnet by spherical edged brass rollers S in such a way as to allow complete freedom of movement longitudinally. The contact points are operated by a rocker or throw-over mechanism in dependence upon the movement of the armature so as alternately to close and open the circuit. The rate of movement of the diaphragm is varied automatically in accordance with the demand for fuel by the engine.

Fuel Reserve. Most drivers greatly appreciate a reliable warning when the petrol tank is nearly empty. Reserve petrol taps cannot conveniently be applied to rear tanks, which are now practically universal, without

some method of remote control for which electrical operation is specially adaptable. In the Lucas reserve
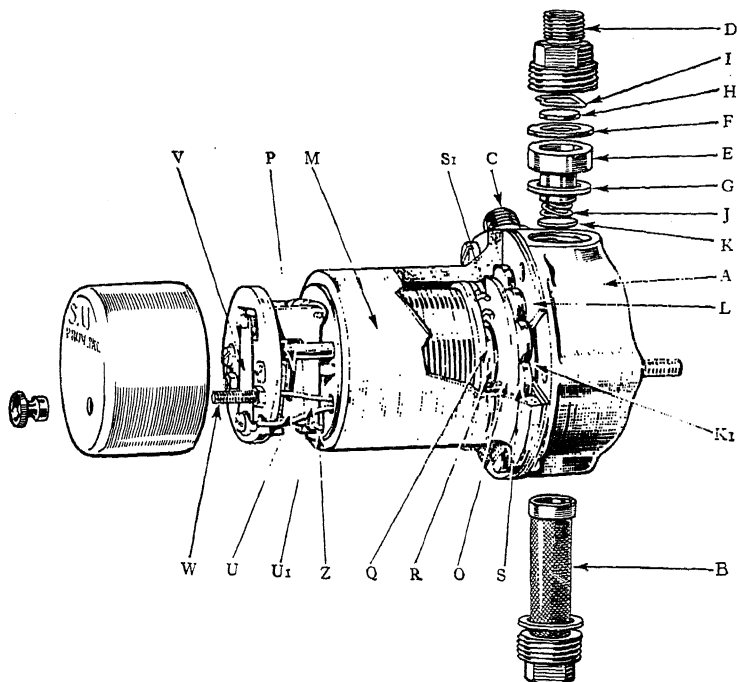

Fig. 146. S.U. Pressure Pump

petrol valve, mounted on top of the tank, the driver can change from the main to the reserve petrol supply by operating a switch on the instrument panel. The reserve depth of petrol equals the difference between the lengths of the two suction pipes. Petrol is normally supplied through both suction pipes to the outlet tube as shown, the control switch being in the off or main supply position. When the petrol level is too low to

cover the end of the main pipe, and air enters the outlet
tube, the hesitation of the engine warns the driver,
who then moves the switch to the main position in
which the solenoid is energized and seats the ball valve,
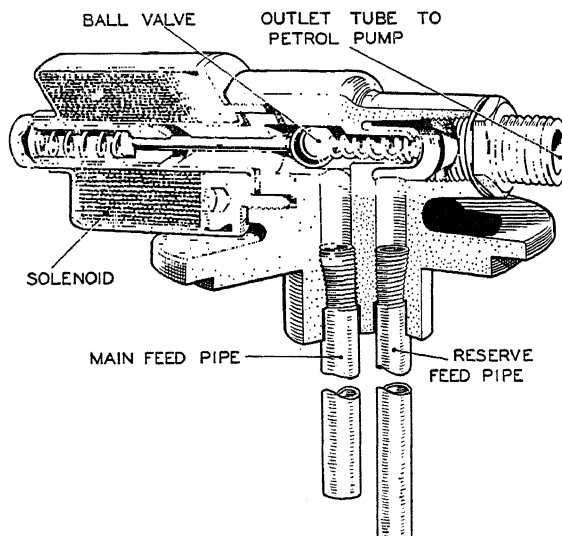
FIG. 147. LUCAS PRESSURE FUEL UNIT .

thus closing the main pipe. The solenoid core seats the
ball through a strong spring and push rod against the
resistance of a weak spring so that it is held either on
or off its seat by springs.

To avoid any risk of sparking due to a loose earth
connection in the neighbourhood of the petrol tank,
the earth return wire from the solenoid is led to some
point well remote from the tank.

Windscreen-wiper. This indispensable accessory can
be driven mechanically or by suction from the engine,
or electrically, the electric method being most widely

used. One of the simplest forms includes a specially
shaped unwound rotor, and a core, also specially
shaped, with a simple winding, the current through
which is continually made and broken by a cam on
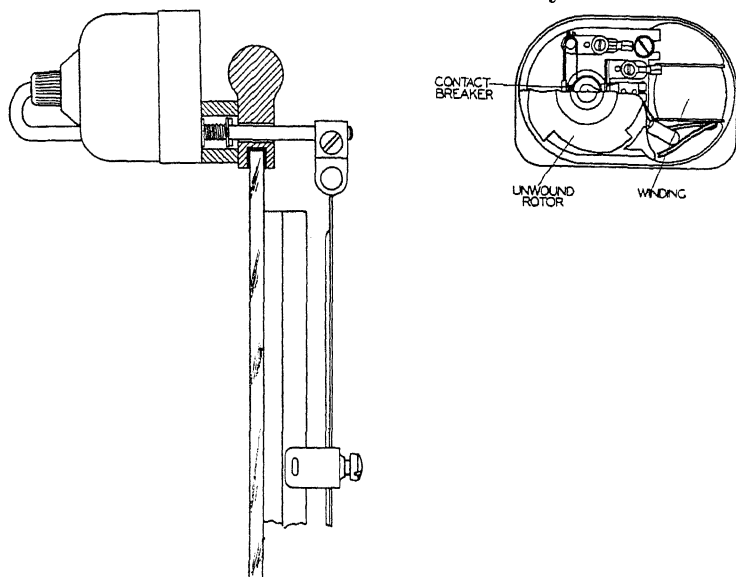
FIG. 148. INDICATOR TYPE SCREEN-WIPER

the spindle of the rotor, which turns at high speed,
and is geared down to the spindle of the wiper. This
construction is shown in Fig. 148. It is not self-
starting, but the knob which is pulled out to switch
on the current, rotates with the rotor and has to be
turned to start the movement. The wiper is provided
with a so-called parking device which permits the blade
to be uncoupled from the driving mechanism and turned
to a horizontal position out of the driver's line of sight,
the arm by which this is effected being adapted to

engage the knob and hold it in the inner or open switch position.

A simple self-starting form of windscreen-wiper operating mechanically is shown in Fig. 149, as supplied by C.A.V.-Bosch Ltd. for commercial purposes. A small shunt-wound electro motor drives through a
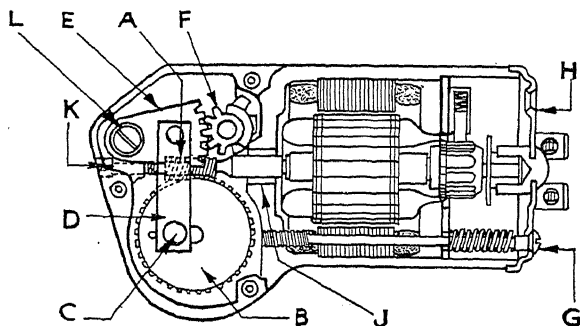
FIG. 149. C.A.V.-BOSCH SELF-STARTING WIPER

high reduction gear a worm wheel *B* which carries a crank pin *C* and oscillates a lever *E* mounted on pivot *L* by means of a link *D*. A toothed sector on the end of lever *E* also meshes with a similar sector *F* on a spindle to which the arm carrying the squeegee is secured. The armature can be removed for inspection and attention by releasing the cover—which is secured by screws *G*. The armature shaft and worm *A* are set lengthwise by screw *K*.

The demand for twin wipers, arranged to provide a clear view for the passenger as well as the driver, presents certain difficulties. It is desirable that only one motor should be used both for the sake of economy and to ensure synchronized operation of the two wiping arms, so as to avoid leaving a large unwiped area in the middle of the windscreen. This has been done in

various ways, the spindles of the two arms being connected by a rotating shaft, or a reciprocating rack, or chains, or links. More recently an attempt has been made to build the twin windscreen-wiping mechanism into the dashboard of the car, and to arrange the motor in front of the dashboard beneath the scuttle. This allows a larger motor to be used, and its operating noise is no longer noticeable.

A Dual Arm Wiper made by Joseph Lucas is shown in Fig. 150, the motor being mounted on the engine side of the dash, and including a reduction gearbox which drives a final shaft, having a flexible rubber coupling. The end of this shaft is fitted with a crank connected by links to two clutch boxes mounted out of sight below the windscreen rail, only the parking knobs being visible. Declutching and parking of the blade is effected by pushing in the knob and turning it until the arm lies on the scuttle. One knob operates the switch.

The building of the screen-wiper arrangement into the structure of the car necessitates pivoting of the wipers near the lower edge of the windscreen which is also hinged at this lower edge, as distinct from the system in which the wipers are arranged near the top of a screen hinged at its upper edge.

Fuses and Circuit Protection. Reference to Fig. 97 showing the complete wiring diagram will disclose a number of fuses arranged at certain critical points. Provision of fuses in all the individual circuits on the vehicle is impracticable on account of the cost and lack of space, and it is often regarded as undesirable on certain technical grounds. Fuses, however carefully manufactured, may produce an element of uncertainty since a defective contact in the holder or a damaged wire may cause premature failure. A fuse is essentially a fine element inserted in a circuit, the wires of which

PARKING PIN

PARKING KNOBS

CLUTCH MECHANISM

SWITCH CONTACTS

DRIVING LINKS
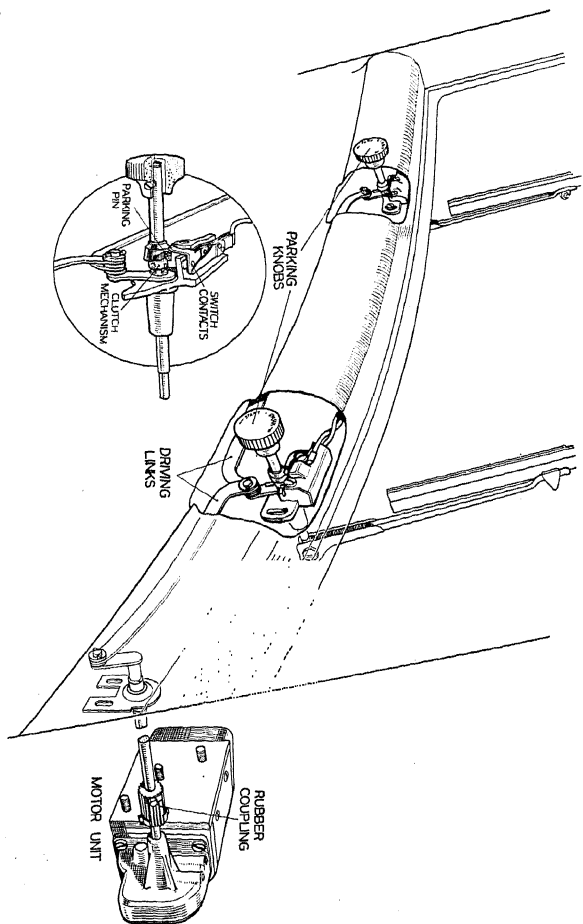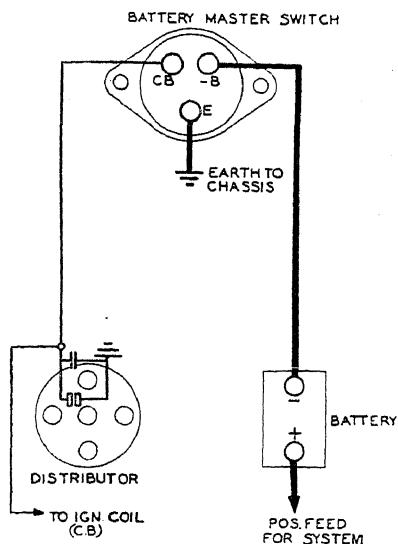
MOTOR UNIT

RUBBER COUPLING

Fig. 150. Lucas Dual Arm Screen-wiper

are of much lower resistance, and the fuse therefore normally works fairly near to its melting point; otherwise it could not be relied upon to break the circuit in the event of an excessive flow of current. Failure of a fuse on certain circuits, for instance, the headlamp circuit of a car, might have serious consequences, and for this reason the headlamp circuit is often not fused, reliance being placed upon careful attention to the wiring and to the installation of the components.

IG. 151. BATTERY MASTER SWITCH
By courtesy of the Institution of Automobile Engineers.)

In certain places, fuses are desirable or even essential. The dynamo is protected by a fuse in its field circuit and sometimes by a larger one in the main circuit. Most of the accessories are supplied through the fuses between terminals $A1-A2$ or $A3-A4$ of Fig. 97. The dipper circuit in the near-side headlamp is connected to earth and is provided with a fuse.

It is desirable that the wiring throughout the car should be sufficient to carry a fairly heavy current, even though the current normally taken by any one component such as an interior lamp is small. It is necessary to use for the accessories fuses of fairly high capacity, such as 25 or 35 amperes to allow the current necessary for the operation of a heavy consumer, such as a

cigar-lighting circuit. If too fine wiring is used for any lightly loaded circuit, such circuit will not be adequately protected by the heavy fuse put in to deal with the greater current required by heavy consumers. Otherwise, it would be necessary to provide fuses of widely differing capacity for different parts, an unsatisfactory practice owing to the possibility of incorrect fuses being used in any particular location.

In connection with this question of protection, reference may be made to the battery master switch, the wiring connections of which are shown in Fig. 151 in connection with a system employing the car frame as a negative earth return. This switch cuts off the supply of battery current from all the electrical circuits in case of emergency and serves also to prevent unauthorized interference and as a precaution against accidents when the car is left in the garage or is unattended. The switch is interposed in the battery earth connection, which it breaks when operated. The contacts should be heavy enough to carry the starter current so that the starter circuit can be disconnected when the other current-consuming components are cut off. It is necessary also to ensure that the engine cannot continue to run when the battery is disconnected. An auxiliary pair of contacts is therefore provided so that when the master switch is actuated the contact-breaker of the ignition system is earthed, thus cutting off the ignition.

INDEX

SECTION XXV

IGNITION, STARTING, LIGHTING, ACCESSORIES